Compilation of a quality-controlled database of biological and chemical oceanographic parameters in the Central Mediterranean Sea

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ABSTRACT The EU-MAST/MEDAR/MEDATLAS II project (Mediterranean Data Archeology and Rescue of temperature, salinity and bio-chemical parameters, 1998-2001) provided the most updated and comprehensive data set and climatological atlas of physical, biological and chemical oceanographic parameters for the Mediterranean and Black Sea. The MEDAR/MEDATLAS II is a distributed data-management structure made up of the NODC/DNA from 20 countries, four regional data centres (in charge of data compilation in the Eastern, Central, and Western Mediterranean and the Black Sea, respectively) and a global assembling centre (responsible for the overall integration). These centres have strengthened the IOC/IODE network at national and regional level, enhancing the overall capacity in data rescue and validation. The multidisciplinary hydrographic data set, globally assembled, was checked for quality by common compatible and coherent procedures, based on international standards. The validation process, fully implemented for temperature, salinity, dissolved oxygen, nitrate, phosphate, and silicate, was extended to other biological and chemical parameters, which include alkalinity, ammonium, chlorophyll-a, nitrite, pH, total phosphorus and total nitrogen. New broad-range check values in the sub-domains' discretisation of the Central Mediterranean were defined. The global analysis of the biological and chemical core parameters defined very wide ranges at the surface, rather wide ones for the intermediate layer, while the ranges are narrow in the deep layer. The statistical results obtained here could be used to improve data management practices, by providing trustworthy intervals to substantiate studies on spatial-temporal variations of selected physical, biological and chemical properties over the past 80 years.

1. Introduction

Data quality assurance is an important issue in oceanographic data management, finalised to the creation of multidisciplinary and comprehensive databases, which include data from different and/or unknown origin covering long time periods. The data-collection methods involve a wide range of instruments, water sample analyses and accuracies. Historical data are often deprived of any detailed information on analytical procedures, calibrations and confidence intervals. The appropriate use of broad-range check values, obtained from large databases, as well as feedback from the scientific community can help focus the data management activity on the validation of new, incoming data.

Comprehensive hydrological observations have been actively conducted in the Mediterranean Sea over the last two decades, accumulating a large amount of multidisciplinary oceanographic data. At the same time, the interpretation and the systematic studies of these data have experienced important variations, that have stimulated further initiatives for the rescue of historical data useful for investigation of the natural and/or anthropogenic impacts on the climatic changes of the marine environment (Bethoux *et al*., 1990; Rohling and Bryden, 1992; Roether *et al*., 1996; Lascaratos *et al*., 1999). The European Union devoted financial resources to develop research infrastructures and the MEDAR/MEDATLAS II project, a MAST/INCO concerted action, was launched with the objective of rescuing, archiving and making quality controlled *in-situ* hydrographic data (physical, biological and chemical parameters) of the Mediterranean and Black Seas available, through a wide co-operation of scientists from bordering countries and international organizations. A distributed regional data centre approach was first established in the Mediterranean Sea in the frame of the EU-MAST/MTP II/MATER project (1996-2000), that resulted in the collection of a large amount of wide-specturum multidisciplinary parameters (Maillard *et al*., 2002). For the MEDAR/MEDATLAS II project, the data management structure was organized within a system of regional and thematic data centres, that provides links between several international programmes. The regionally distributed network was made up of NODC/DNA (National Oceanographic Data Centers/Designed National Agencies) within the Intergovernmental Oceanographic Commission (IOC)'s International Oceanographic Data Exchange (IODE) System from 20 countries, four regional data centers (Instituto Espanol de Oceanografia - IEO in Spain, Istituto Nazionale di Oceanografia e di Geofisica Sperimentale - OGS in Italy, National Centre for Marine Research - NCMR in Greece, Russian Scientific Research Institute of HydroMeteorological Information - RIHMI in Russia) responsible for the data pertinent to the Western Mediterranean, the Central Mediterranean, the Eastern Mediterranean and the Black Sea, respectively. The global assembling center was established at the Institut Francais de Recherche pour l'Exploitation de la Mer - IFREMER in France to merge the four databases. The Central Mediterranean area data (i.e. Adriatic, Ionian, Tyrrhenian and Ligurian Seas), were assembled through close collaboration with the national marine research laboratories located in Italy, Malta and Croatia, which actively operate in oceanographic data collection through national and international projects. Data and related information (meta-data) were rescued, fully validated and archived, according to methods and standards established in the common protocol. Inventories of all available data and related information were compiled and disseminated through the World Wide Web pages of the project and can now be freely accessed by any scientist.

The qualification and safeguarding of existing oceanographic data and related information was an important issue of this project, aiming at enhancing the overall capacity of the IODE/IOC network and sharing the know-how in oceanographic data management with the participants. Data validation was implemented at regional level, by fully and completely adopting the protocols established at project level. Nevertheless, the system adopted for the Central Mediterranean regions, based on existing objectively analysed and horizontal grid climatologies at prescribed depths of temperature and salinity, shows many inconsistent data quality flags while the data were representative of realistic conditions and perturbations of the presumed steady-state. In addition, a closer inspection of the nutrient profiles revealed that the chosen reference statistics were not defined to finely sensitive, especially for nitrate, phosphate and silicate, due to the scarcity of the existing and archived data and to the inhomogeneous distribution of values pertinent to the intermediate and deep layers.

The main purpose of this study is to present and discuss the main improvements obtained through the MEDAR/MEDATLAS II data management activity, in particular, the validation of physical, biological and chemical parameters in the Central Mediterranean regions. The oceanographic parameters considered include vertical profiles of temperature, salinity, dissolved oxygen, nitrate, phosphate, silicate, alkalinity, ammonium, chlorophyll-a, nitrites, pH, total phosphorus and total nitrogen. In section 1 we assess the total amount of hydrographic data rescued in the regional data center. In section 2 we describe the criteria for data quality control implemented at a regional level, fully and completely adopted at the project level, while in section 3 we present the results from the global analysis of biological and chemical core parameters. In the last section, the three layers' vertical discretisation and the statistical indexes computed in the deep layer are discussed together with some concluding remarks about this work.

2. MEDAR/MEDATLAS II data assembled in the Central Mediterranean Sea

Historical databases and climatological atlases related to the Mediterranean Sea available to the broad scientific community include those of Miller *et al*. (1970), Levitus (1982), Guibout (1987), Picco (1990), and Levitus *et al*. (1994, 1998). The MODB and MEDATLAS twin initiatives (MODB Group, 1996; MEDATLAS Consortium, 1997), funded by the Marine Science and Technology Programme of the European Union (EU/MAST) during the period 1994-1996, provided an updated and quality controlled version of the temperature and salinity data set in the Mediterranean Sea and revised the already traced horizontal climatologies (Brasseur *et al*., 1996; Jourdan *et al*., 1997).

The EU-MAST/MEDAR/MEDATLAS II project doubled the volume of physical observations available in the Mediterranean and Black Seas and extended the previous databases to some additional biological and geo-chemical parameters (MEDAR Group, 2001b). The hydrological stations for the Central Mediterranean region, were provided by the national partners as follows: (i) IOF, Institute of Oceanography and Fisheries, Split, Croatia; (ii) OGS, Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Trieste, Italy; (iii) UM-PO, University of Malta, Physical Oceanographic Unit, Malta; and (iv) ENEA/Centro Ricerche per l'Ambiente Marino, La Spezia, Italy. The total amount of hydrological stations available from MEDATLAS I and the new data supplied to the regional data center are listed in Table 1, and classified according to the sampling strategies. The data sets rescued at OGS derive from scientific co-operation among national and international laboratories, which participated in basin-wide research cruises, set up in the framework of national (e.g. CNR/PF Oceanagrafia e Fondi Marini, MIUR/PRISMA, etc.)

Table 1 - Number of hydrological stations extracted from MEDATLAS I and the new data assembled at the regional data center for the Central Mediterranean within MEDAR/MEDATLAS II.

	XBT Stations	CTD Stations	Bottle Stations
MEDATLAS I	33.566	9.265	18.083
OGS Trieste, Italy	0	5.670	8.781
UM-PO Malta	0	179	129
IOF Split, Croatia	0	163	0
ENEA/CRAM, Italy	39	0	159
TOTAL	33.605	15.277	27.152

and international programmes (e.g. ASCOP, POEM, PRIMO, EU/MAST/MTP I and II programmes, etc.). These data, owned by OGS, were collected by nine Italian scientific laboratories: CNR - Istituto di Biologia Marina of Venezia, CNR - Istituto di Fisica dell'Atmosfera of Roma, CNR - Istituto di Geologia Marina of Bologna, CNR - Istituto di Oceanografia Fisica of La Spezia, CNR - Istituto di Ricerca sulla Pesca Marittima of Ancona, CNR - Istituto Talassografico of Trieste, University "Parthenope" - Istituto di Meteorologia ed Oceanografia of Napoli, and Stazione Zoologica "Anton Dohrn" of Napoli. In addition, two large historical data collections for the Adriatic Sea of physical and bio-chemical parameters were considered. They were extensively analysed by Artegiani *et al*. (1997) and by Zavatarelli *et al*. (1998), and replaced the old version that had been included in the MEDATLAS I database.

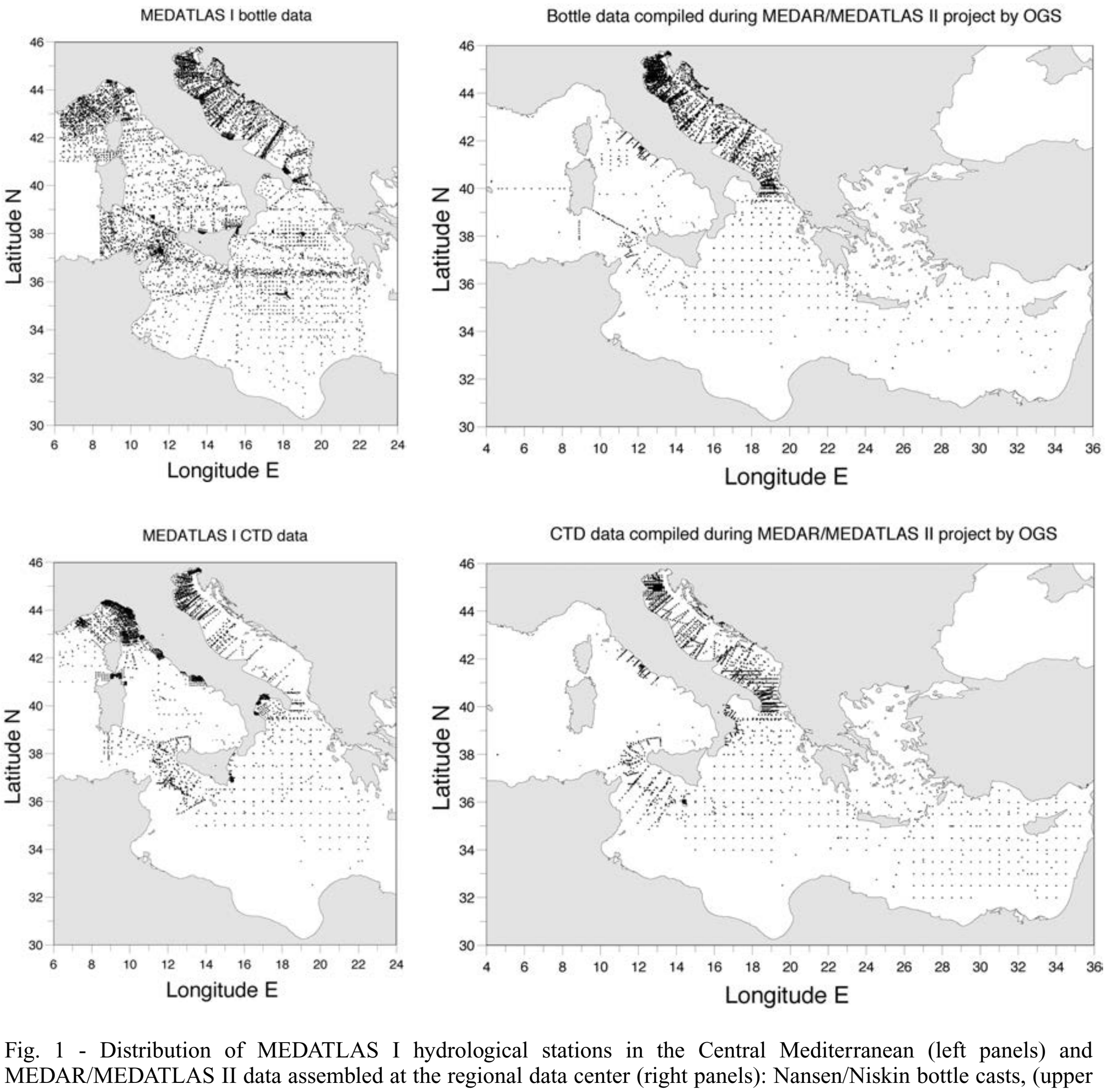


Fig. 1 - Distribution of MEDATLAS I hydrological stations in the Central Mediterranean (left panels) and MEDAR/MEDATLAS II data assembled at the regional data center (right panels): Nansen/Niskin bottle casts, (upper panels), CTD casts (lower panels).

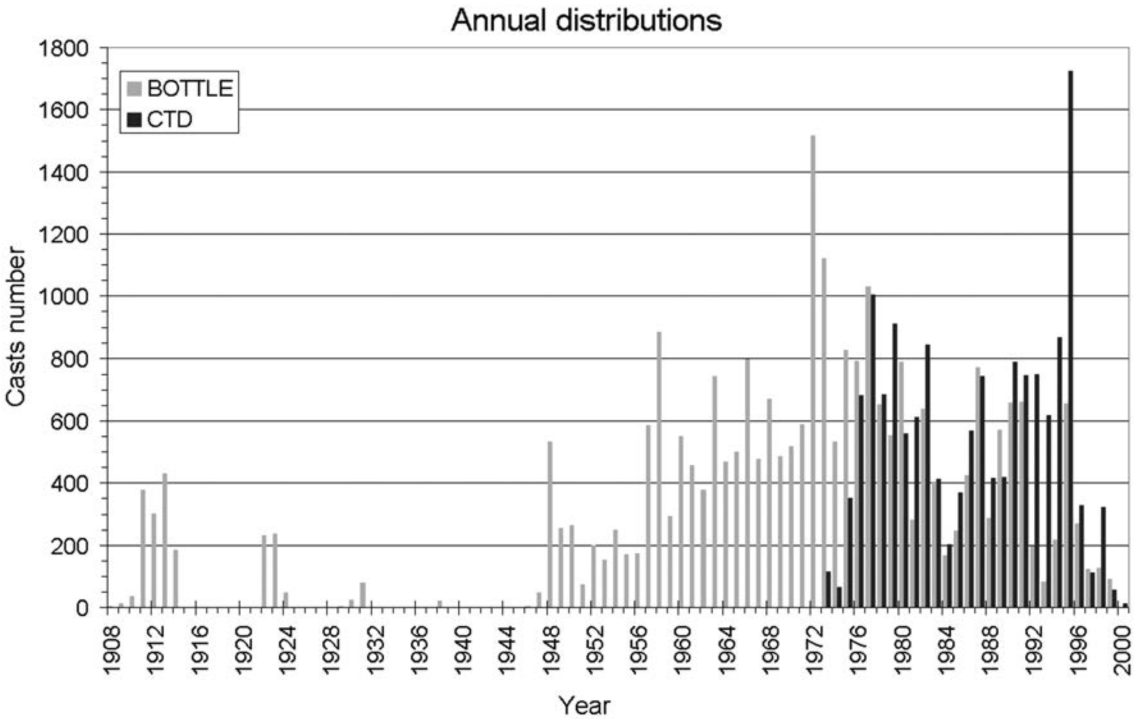
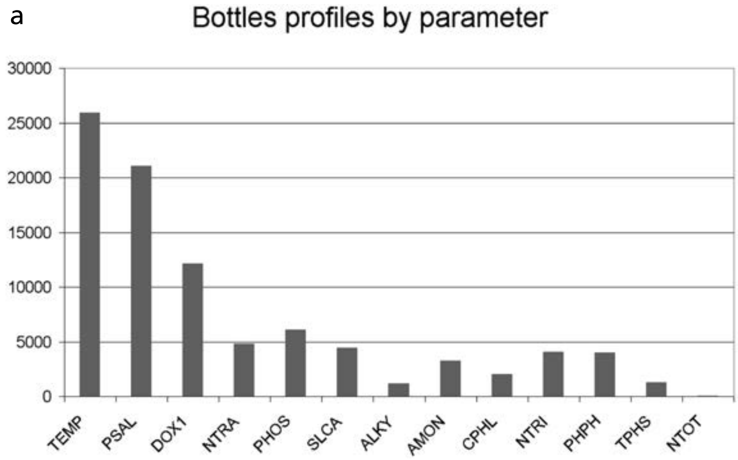


Fig. 2 - Temporal distribution of MEDAR/MEDATLAS II hydrological stations related to the Central Mediterranean: Nansen/Niskin bottle casts (gray scale) and CTD casts (black scale).

Fig. 1 depicts the bottle and CTD hydrological stations assembled at the regional data center, where the already available MEDATLAS I database exclusively for the Central Mediterranean, and the new stations recovered by the MEDAR/MEDATLAS II are highlighted. The spatial coverage is still not uniform, since some areas in the South-Western and Central Ionian Sea still remain unexplored. The data related to the Eastern Mediterranean are part of multi-ship basin scale experiments conducted at a quasi-synoptic time scale. These represent the most updated versions of the International POEM data obtained after performing intercalibration exercises. The global data set presents a rather heterogeneous time distribution as well. Bottle casts cover the years going from 1908 up to 1999, but the majority of the stations' data were collected after the Fifties. The CTD data cover the period from the early Seventies onwards. The distribution per year of bottle stations (grey scale), and CTD profiles (black scale), is given in Fig. 2.

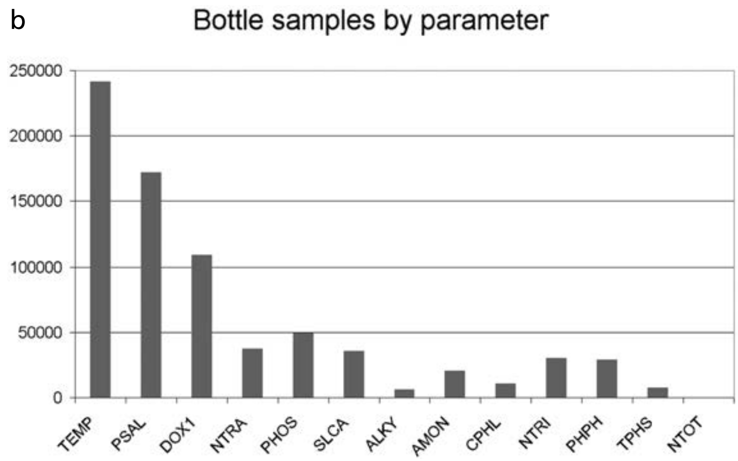
The complete list of parameters includes observations of physical, biological and chemical oceanographic properties, some bio-optical properties as light penetration, bio-mass, some isotopic elements in the water column, as well as physical and chemical elements in the suspended matter (MEDAR Group, 2001a). For the purpose of this work, we bear our analyses to the bottle data, that include observations of temperature, salinity, dissolved oxygen, nitrate, phosphate, silicate, alkalinity, ammonium, chlorophyll-a, nitrite, pH, total phosphorus and total nitrogen. Fig. 3 shows the total number of bottle stations and the total number of samples rescued for each parameter in the central region of the Mediterranean Sea.

a



		Profiles
TEMP	- Temperature	25952
PSAL	- Salinity	21049
DOX1	- Dissolved Oxygen	12124
NTRA	- Nitrate	4837
PHOS	- Phosphate	6081
SLCA	- Silicate	4440
ALKY	- Alkalinity	1150
AMON	- Ammonium	3278
CPHL	- Chlorophyll-a	2045
NTRI	- Nitrite	4087
PHPH	- PH	4013
TPHS	- Total Phosphorus	1276
NTOT	- Total Nitrogen	27

b



		Samples
TEMP	- Temperature	241336
PSAL	- Salinity	172069
DOX1	- Dissolved Oxygen	109297
NTRA	- Nitrate	37634
PHOS	- Phosphate	49469
SLCA	- Silicate	35482
ALKY	- Alkalinity	6392
AMON	- Ammonium	20396
CPHL	- Chlorophyll-a	10848
NTRI	- Nitrite	30381
PHPH	- PH	28939
TPHS	- Total Phosphorus	7358
NTOT	- Total Nitrogen	92

Fig. 3 - MEDAR/MEDATLAS II bottle station distribution by parameter in the Central Mediterranean: (a) total number of profiles, (b) total number of samples.

3. Quality control of the incoming data within MEDAR/MEDATLAS II

Major attention was given, in MEDAR/MEDATLAS II project, to the quality control of incoming data, necessary to ensure coherence and compatibility with the earlier archived data sets and with non-physical parameters. The MEDAR/MEDATLAS II protocol (Maillard *et al.*, 2001) was designed according to guidelines and international standards provided by UNESCO/IOC and ICES (UNESCO, 1993) within the IODE system and the GODAR (Global Ocean Data Archaeology and Rescue) programme. Former protocols and experience gained in other MAST data management activities, i.e. the pilot MEDATLAS (MAS2-CT93-0074), MODB (MAS2-CT93-0075-BE) and MTPII/MATER projects in the Mediterranean Sea, were considered as well. Accordingly, the values measured were not modified, but a quality flag was added to each numerical observation. For recent data, the originator was contacted to take the necessary action to eliminate outliers before archiving the data. The flag values are those adopted within the Global Temperature and Salinity Profile Program (GTSPP) and are proportional to the level of error. They span from 1, to indicate good data, to 5, in the case of modified values. The flag value 0 means no quality control was performed. The quality control procedure includes a series of automatic, and therefore objective tests and a visual inspection, which is somehow subjective but not arbitrary. The data processing includes three steps: (i) the QC-0 level, to check the format and the completeness of the documentation in accompanying of the measured data (e.g. ship's name, cruise, codes, etc.); (ii) the QC-1 level, to check the station header format including date and location revealing duplicate stations, which is a major problem merging new data with the historical one; (iii) the QC-2 level, to check the parameter data by comparing each observation with available range values. The latter includes the broad range check (i.e. the comparison with a minimum and a maximum regional value, flag 4 in case of failure), the narrow range check (i.e. the comparison with pre-existing climatology, computed along the vertical, flag 2 in case of failure), the check for spikes (flag 3 in case of failure), and finally the check for vertical stability (flag 4 in case of failure). The broad-range check has a different meaning with respect to the narrow-range check. The former aims to put in evidence the obvious erroneous values (bad data), while the latter highlights the fact that the observation is not represented by the existing climatologies. The distance allowed to the reference climatology depends on the location of the station (i.e. over the shelf, at the slope and straits regions, in the open sea) and varies between 3, 4 and 5 times the standard deviation, respectively. The reference climatologies were those computed from MEDATLAS 1997 data set for temperature and salinity (MEDATLAS Consortium, 1997), and those computed from WOD98 data set (Levitus *et al*., 1998) for nutrient profiles. They were spatially averaged over 1x1 degree squares and calculated over a limited number of standard levels. The quality control protocol was that implemented at a project level and tuned at a regional level according to the local oceanographic characteristics.

The broad range control values initially decided for the basic core parameters have been discussed, revised and improved, and new geographic limits were defined for the sub-domains's discretisation in the Central Mediterranean Sea. Table 2 presents the geographic limits for the

Table 2 - Geographical limits of the regional sub-domains discretisation of the Central Mediterranean as used for broad-range scale definition and the corresponding maximum depth.

Code	Region Name	Lat. min	Lat. max	Lon. min	Lon. max	Max depth
DJ1	North Adriatic	42 00′	46 00′	12 10′	13 50′	150 m
DJ2	Middle Adriatic	41 18′	46 00′	13 50′	16 16′	270 m
DJ3	South Adriatic	40 36′	44 00′	16 16′	20 00′	1350 m
DJ4	NE Ionian	38 00′	40 36′	18 00′	22 30′	3650 m
DJ5	S Ionian	30 00′	35 10′	15 00′	22 30′	4300 m
DJ6	NW Ionian	38 00′	40 36′	16 16′	18 00′	2770 m
DJ7	Middle Ionian	35 10′	38 00′	15 00′	22 30′	5100 m
DI3	Sicily Strait	30 00′	38 00′	10 00′	15 00′	1550 m
DI1	Sardinia Strait	36 00′	39 18′	8 24′	10 00′	2660 m
DT1	NW Tyrrhenian	39 18′	42 48′	9 18′	13 48′	3100 m
DT2	NE Tyrrhenian	39 18′	41 18′	13 48′	16 16′	3100 m
DT3	S Tyrrhenian	38 00′	39 18′	10 00′	16 16′	3100 m
DF3	W Ligurian	41 00′	45 00′	6 18′	9 18′	2900 m
DF4	E Ligurian	42 48′	45 00′	9 18′	11 00′	1050 m

regional sub-domains pertinent to the Central Mediterranean and the corresponding maximum depth, as resulted from the U.S. Navy Digital Bathymetric Map with a resolution of 1/12° x 1/12°. Accordingly, in these are graphically represented in Fig. 4. Basically, the new sub-domains were defined in the Adriatic Sea making a more accurate distinction between the Northern, the Middle and the Southern Adriatic basins. In the Tyrrhenian Sea, three sub-domains were grouped since a finer subdivision, as initially proposed in the protocol, was considered beyond the scope of the quality control for impossible regional values (QC-2, flag 4). The broad range values were defined separately for the upper layer (0-200 m) and the intermediate/deep layers (201-bottom),

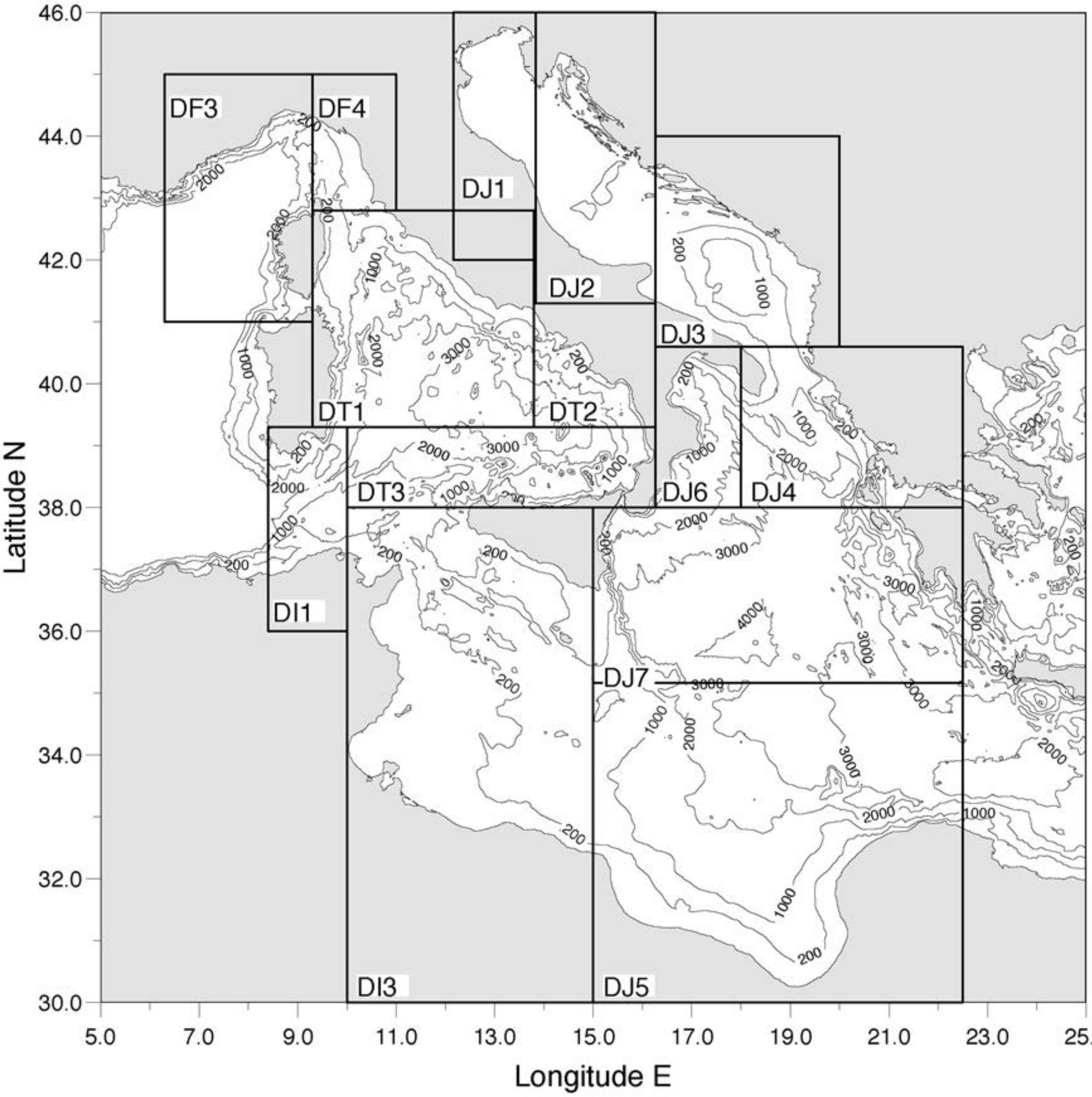


Fig. 4 - Regional sub-domains defined in the Central Mediterranean for the broad range check.

according to the steady thermohaline circulation of the Mediterranean Sea. The upper thermohaline circulation is closely exemplified by the coexistence of two water masses: (i) the less saline Atlantic Water that flows eastwards in the upper layer, and (ii) the more saline Levantine Intermediate Water that spreads westwards in the intermediate layer. The latter, being subject to further transformation, is entrapped into the deep layer during the winter, in correspondence to the major topographically controlled cyclonic gyres, and spreads throughout the whole basin. Furthermore, the circulation patterns and the water properties in the upper layer may be easily altered in proximity of the coastal area due to the river runoff and to the enhanced biological activity. A compromise has been reached in consideration of a very large variability that may affect the coastal zone. However, priority has been given to a better qualification of the off-shore stations, and the broad range values has been defined in order to minimise erroneous or non-representative observations that may create unreal features in the open sea climatological analyses. In consideration of a very limited number of stations in the historical databases for the bio-chemical parameters, the minimum and maximum values were adjusted to encompass the time-space variability experienced from data collected during recent projects. The final broad-range check values of thermohaline and nutrient core elements are summarised in Table 3. To perform the narrow-range checks, seasonal mean climatological profiles of temperature and salinity were computed from MODB data (MODB Group, 1996), while WOD98 annual mean climatological profiles of dissolved oxygen, nitrate, phosphate and silicate (Levitus *et al.*, 1998) were considered.

4. Vertical distributions of biological and chemical oceanographic core parameters

Statistical analyses of the biological and chemical core parameters were performed in the 14 sub-domains of the Central Mediterranean Sea, as defined in Table 2, by using the comprehensive MEDAR/MEDATLAS II hydrographic data set. This study aimed at extending the broad-range check values, already defined for temperature, salinity oxygen and primary nutrients, to additional parameters archived within the project, and for which comprehensive reference statistics were not available. Figs. 5 to 8 show the vertical distributions of alkalinity, ammonium, chlorophyll-a, nitrite, pH and total phosphorus in the sub-domains of the Adriatic Sea (Fig. 5), in the Ionian Sea (Fig. 6), in Sicily, Sardinia, the South Ionian Sea (Fig. 7), in the Ligurian and Tyrrhenian Seas (Fig. 8). Total nitrogen has been analysed as well (not shown), including a few stations, but only in the Adriatic Sea sub-domains. The parameter plots are presented on a full scale for all available data in order to give an indication of the dispersed data values. The ranges include wrong observations (see for example total phosphorus in the Northern Adriatic) or instrumental errors (see for example nitrite in the Strait of Sicily). Nevertheless, the vertical variability of biological and chemical properties along the water column, as well as the spatial variability in different sub-domains, emerge. It is clearly evident that the number of available data is highly inhomogeneous from parameter to parameter and from region to region. The South-Eastern Tyrrhenian (DT2) and the Eastern Ligurian (DF4) sub-domains, presenting only a few values of nitrite and pH, are not shown. In these cases, the broad range values have been defined according to the adjacent areas and should be revised as soon as new data is be made available.

The Adriatic Sea (Fig. 5) exhibits a general decrease in concentrations and in dispersions from

Table 3 - Minimum and maximum control values for the two layers (0-200 m, 201-bottom) in the Central Mediterranean regions as used for the broad-range check of hydrological core parameters.

	Sea Temperature (°C)				Salinity (pss)			
DJ1 - North Adriatic	5	28	/	/	24	39	/	/
DJ2 - Middle Adriatic	8	28	8	16	30	39	30	39
DJ3 - S Adriatic	8	28	10	16	36	39	36	39
DJ4 - NE Ionian	10	30	12	16	36	40	37	40
DJ5 - S Ionian	12	30	12	17	37	40	38	40
DJ6 - NW Ionian	12	29	12	16	36	39	37	39
DJ7 - Middle Ionian	12	30	13	17	37	40	38	40
DI3 - Sicily Strait	12	28	12	16	36	39	36	39
DI1 - Sardinia Strait	12	28	12	16	36	39	36	39
DT1 - NW Tyrrhenian	12	28	12	15	37	39	38	39
DT2 - NE Tyrrhenian	12	28	12	15	37	39	38	39
DT3 - S Tyrrhenian	12	28	12	15	37	39	38	39
DF3 - W Ligurian	10	29	12	16	36	39	38	39
DF4 - E Ligurian	11	28	12	16	36	39	38	39
	Dissolved Oxygen (ml/l)				**Nitrate (mmole/m^3)**			
DJ1 - North Adriatic	0	10	/	/	0	16	/	/
DJ2 - Middle Adriatic	3	9	2	9	0	9	0	9
DJ3 - S Adriatic	3	9	3	8	0	9	0	9
DJ4 - NE Ionian	3	8	3	6	0	9	0	9
DJ5 - S Ionian	3	8	3	6	0	9	0	11
DJ6 - NW Ionian	3	8	3	6	0	9	0	9
DJ7 - Middle Ionian	3	8	3	6	0	9	0	9
DI3 - Sicily Strait	3	8	3	6	0	9	0	12
DI1 - Sardinia Strait	3	8	3	6	0	9	0	12
DT1 - NW Tyrrhenian	3	8	3	6	0	9	0	9
DT2 - NE Tyrrhenian	3	8	3	6	0	9	0	9
DT3 - S Tyrrhenian	3	8	3	6	0	9	0	11
DF3 - W Ligurian	3	8	3	6	0	7	0	9
DF4 - E Ligurian	3	8	3	6	0	7	0	9
	Phosphate (mmole/m^3)				**Silicate (mmole/m^3)**			
DJ1 - North Adriatic	.0	1.5	/	/	0	60	/	/
DJ2 - Middle Adriatic	.0	1.0	.0	1.0	0	20	0	26
DJ3 - S Adriatic	.0	1.0	.0	1.0	0	11	0	25
DJ4 - NE Ionian	.0	1.0	.0	1.0	0	10	0	16
DJ5 - S Ionian	.0	1.0	.0	1.0	0	9	0	11
DJ6 - NW Ionian	.0	1.0	.0	1.0	0	9	0	11
DJ7 - Middle Ionian	.0	1.0	.0	1.0	0	9	0	11
DI3 - Sicily Strait	.0	1.0	.0	1.0	0	9	0	12
DI1 - Sardinia Strait	.0	1.0	.0	1.0	0	9	0	12
DT1 - NW Tyrrhenian	.0	1.0	.0	1.0	0	9	0	10
DT2 - NE Tyrrhenian	.0	1.0	.0	1.0	0	9	0	10
DT3 - S Tyrrhenian	.0	1.0	.0	1.0	0	9	0	12
DF3 - W Ligurian	.0	1.0	.0	1.0	0	9	0	11
DF4 - E Ligurian	.0	1.0	.0	1.0	0	9	0	11

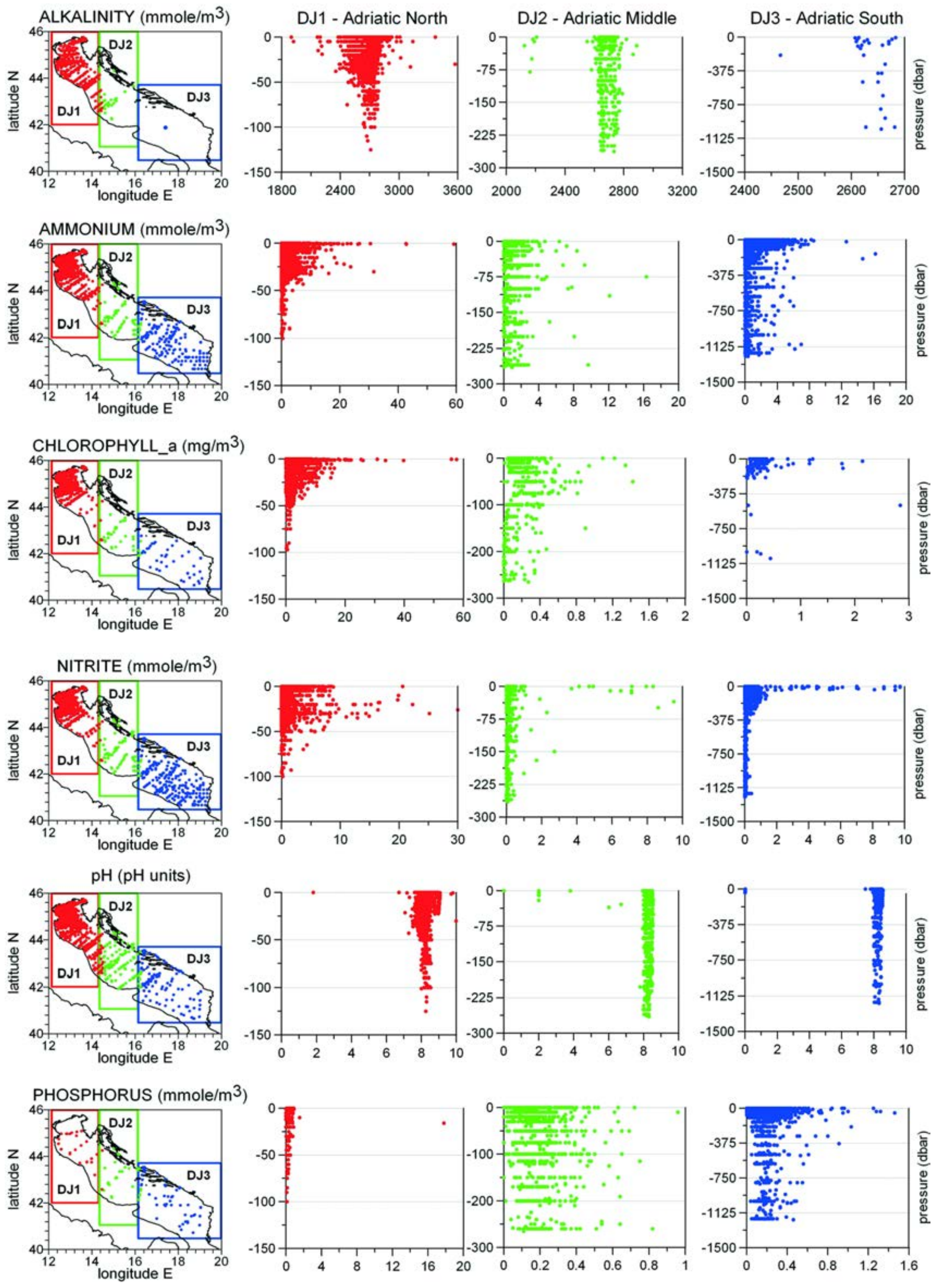


Fig. 5 - Vertical distributions of biological and chemical core parameters (alkalinity, ammonium, chlorophyll-a, nitrite, pH and total phosphorus) in the Adriatic Sea.

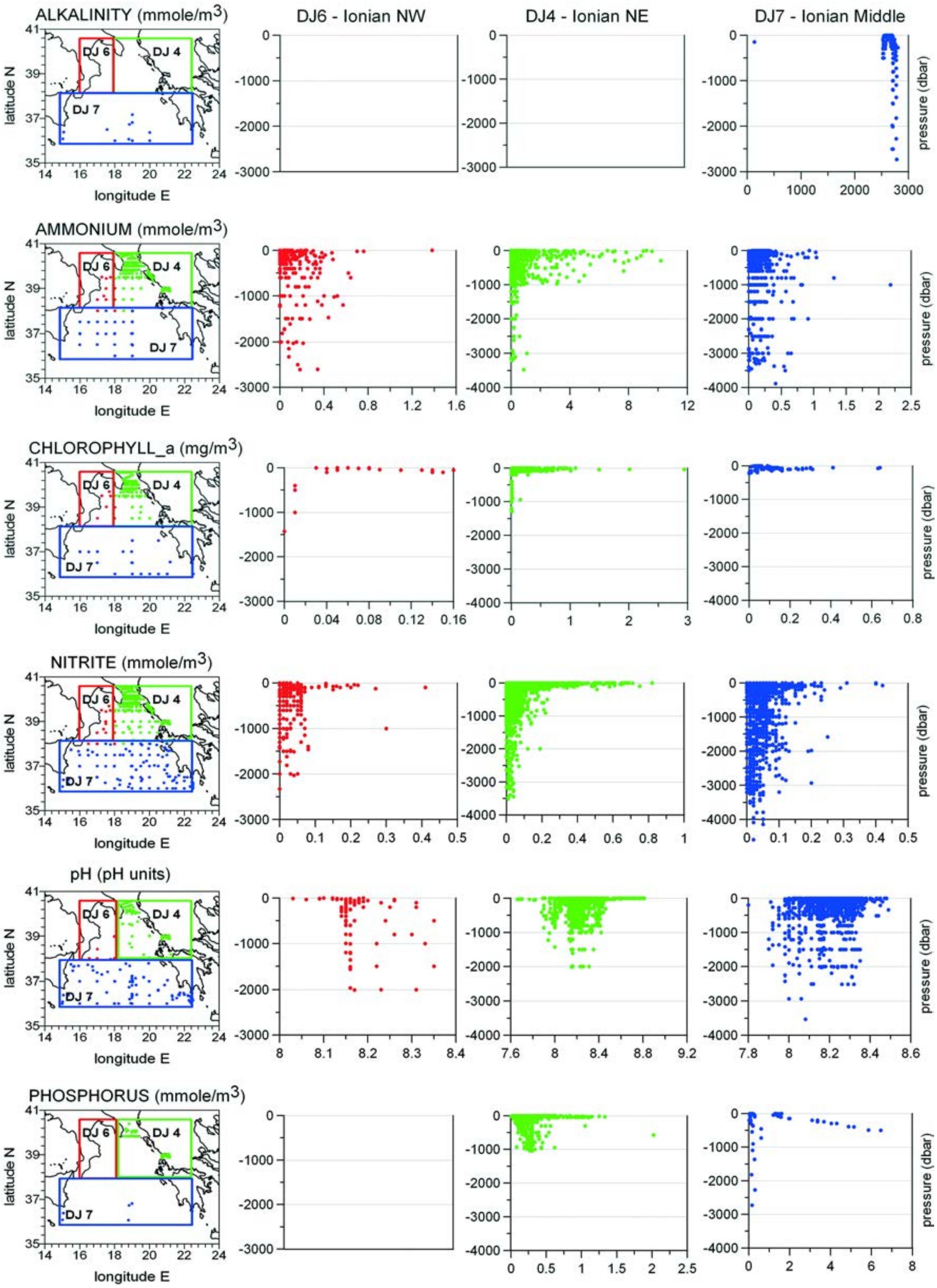


Fig. 6 - Vertical distributions of biological and chemical core parameters (alkalinity, ammonium, chlorophyll-a, nitrite, pH and total phosphorus) in the Ionian Sea.

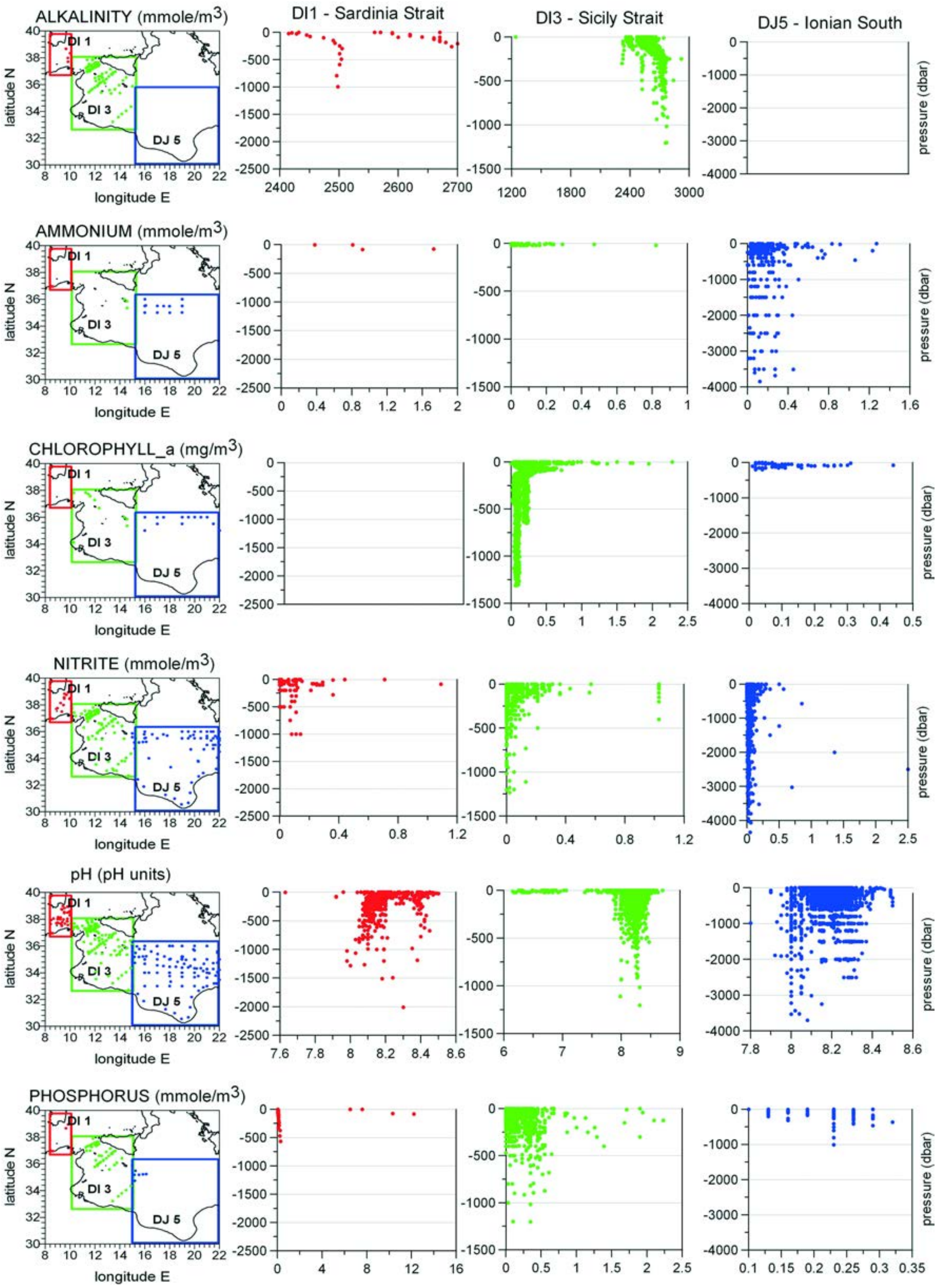


Fig. 7 - Vertical distributions of biological and chemical core parameters (alkalinity, ammonium, chlorophyll-a, nitrite, pH and total phosphorus) in the Sicily, Sardinia, South Ionian Sea.

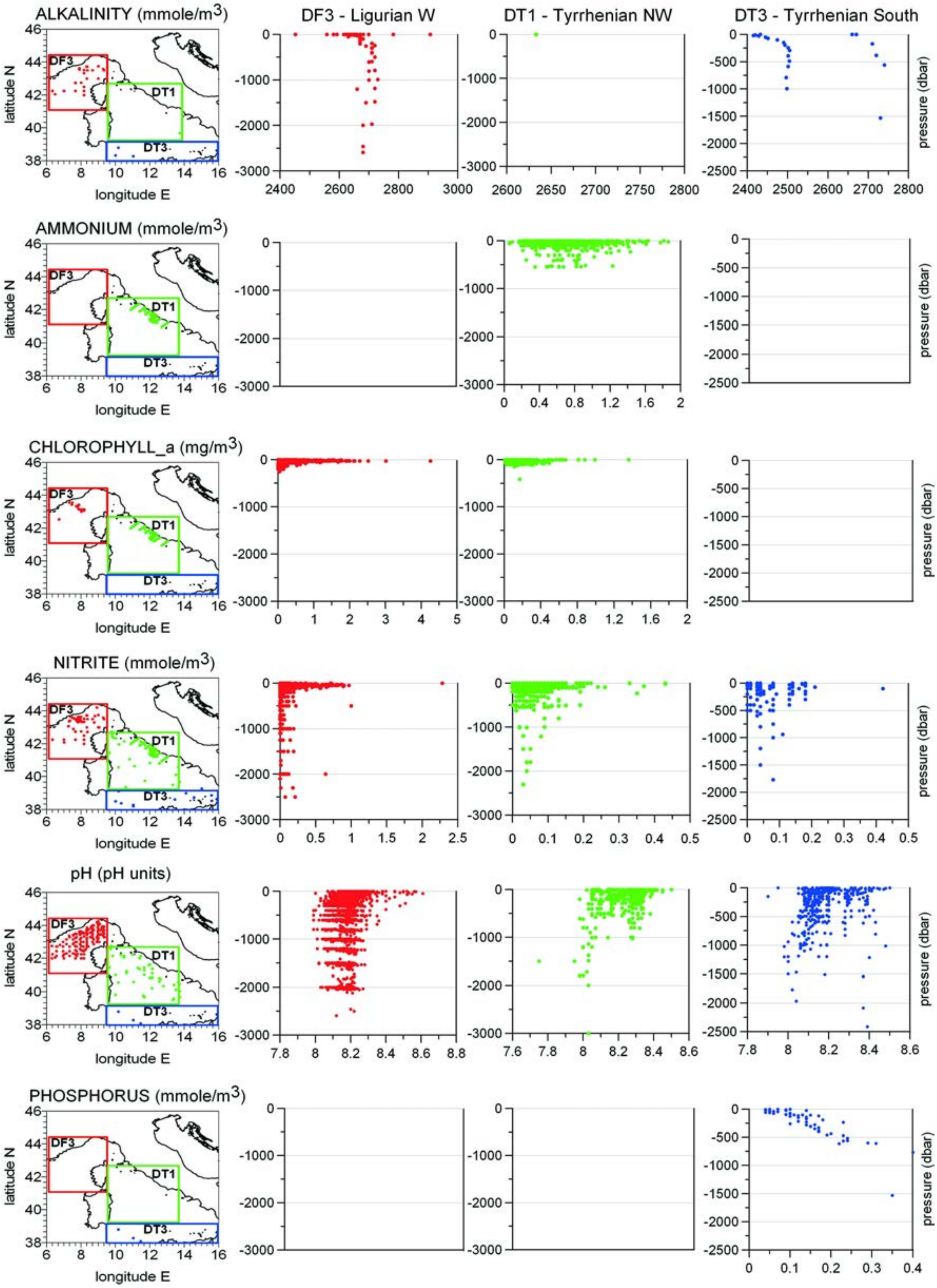


Fig. 8 - Vertical distributions of biological and chemical core parameters (alkalinity, ammonium, chlorophyll-a, nitrite, pH and total phosphorus) in the Ligurian and Tyrrhenian Seas.

north to south, due to river-in inputs occurring mainly in the northern areas. Accordingly, the Northern Adriatic is the sub-domain with the broadest limits, defined as a compromise between flagging wrong values in the open sea and keeping correct measures representative of the strong eutrophic ecosystem. The variability in the north-eastern part of the Ionian Sea (Fig. 6) is larger than that of the western part (see for example ammonium high values), highlighting the permanent water exchange regime with the Adriatic Sea, through the Strait of Otranto. The Ionian South, Strait of Sicily and Strait of Sardinia sub-domains (Fig. 7) evidence low values of ammonium, chlorophyll and nitrite. Data distributions are rather heterogeneous: only nitrite and pH concern the entire water column, while the ammonium in the Strait of Sicily covers only the surface layer. Total phosphorus in the Strait of Sardinia shows values ten times greater than the normal values. The Tyrrhenian and Ligurian Seas (Fig. 8) show a large variability, probably ascribable to the huge Rhone river nutrient input.

The visual inspection of vertical profiles in one sub-domain, combined with those of the adjacent areas, has provided valuable information in checking for possible erroneous data. However, the assistance of experts in biological and chemical oceanography was necessary to take the final decision in flagging these parameters' data. Tables 3 and 4 summarise the broad-range values of hydrological core parameters and of alkalinity, ammonium, chlorophyll-a, nitrite, pH, total phosphorus and total nitrogen in each sub-domain of the central Mediterranean. Table 5 summarises the statistics after the application of the updated quality control values (Tables 3 and 4). These results show that 97% or more of the data were qualified as good data (QC=1,2). Only for the total nitrogen is the percentage lower.

5. Conclusive remarks

The data quality control within the framework of the MEDAR/MEDATLAS II project concerned the compilation of the header information for cruises and hydrological stations and the quality check of related observations. In principle, the quality control protocol for the whole Mediterranean has been adjusted regionally. An accurate analysis of the initially agreed-upon control values for each parameter in the different sub-domains and their geographic limits revealed some inconsistencies in quality checking the incoming data. The rescued data were merged with the historical data and the increased number of hydrological stations not only allowed the calculation of more robust vertical climatologies (Manca *et al*., 2004) but also the definition of more appropriate broad-range values for physical, biological and chemical core parameters. Moreover, these values were defined for three layers, where the general circulation of the major water masses develops. In a climatological sense, the upper layer extends down to 200 m and is mostly subject to a large variability due to the atmospheric forcing, to the surface input of nutrients and to the productivity uptake. The intermediate layer (200-800 m) is mostly characterised by advection and mineralization processes, roughly revealed by oxygen decrease and nutrient increase. This layer is mainly characterised by the spreading of the Levantine Intermediate Water (LIW), identified by its salinity maximum. The deep layer, below the 800 m, presents rather uniform physical, biological and chemical characteristics, exhibiting small dispersions of the observations. Nevertheless, a larger spatial variability prevails. A more accurate distinction between the deep and bottom layer is crucial to getting appropriate control

	Alkalinity (mmole/m³)				**Ammonium (mmole/m³)**			
DJ1 - North Adriatic	2000	3000	/	/	.0	30.0	/	/
DJ2 - Middle Adriatic	2500	3000	2500	3000	.0	10.0	.0	7.0
DJ3 - S Adriatic	2500	3000	2500	3000	.0	10.0	.0	7.0
DJ4 - NE Ionian	2500	3000	2500	3000	.0	10.0	.0	7.0
DJ5 - S Ionian	2500	3000	2500	3000	.0	2.0	.0	1.0
DJ6 - NW Ionian	2500	3000	2500	3000	.0	2.0	.0	1.0
DJ7 - Middle Ionian	2500	3000	2500	3000	.0	2.0	.0	1.0
DI3 - Sicily Strait	2500	3000	2500	3000	.0	2.0	.0	1.0
DI1 - Sardinia Strait	2500	3000	2500	3000	.0	2.0	.0	1.0
DT1 - NW Tyrrhenian	2500	3000	2500	3000	.0	2.0	.0	2.0
DT2 - NE Tyrrhenian	2500	3000	2500	3000	.0	2.0	.0	2.0
DT3 - S Tyrrhenian	2500	3000	2500	3000	.0	2.0	.0	2.0
DF3 - W Ligurian	2500	3000	2500	3000	.0	2.0	.0	2.0
DF4 - E Ligurian	2500	3000	2500	3000	.0	2.0	.0	2.0
	Chlorophyll-a (mg/m³)				**Nitrite (mmole/m³)**			
DJ1 - North Adriatic	.0	20.0	/	/	0	10	/	/
DJ2 - Middle Adriatic	.0	2.0	.0	.5	0	3	0	3
DJ3 - S Adriatic	.0	2.0	.0	.5	0	2	0	2
DJ4 - NE Ionian	.0	2.0	.0	.5	0	1	0	0.5
DJ5 - S Ionian	.0	1.0	.0	.5	0	1	0	0.5
DJ6 - NW Ionian	.0	1.0	.0	.5	0	0.5	0	0.2
DJ7 - Middle Ionian	.0	1.0	.0	.5	0	0.5	0	0.2
DI3 - Sicily Strait	.0	1.0	.0	.5	0	0.5	0	0.5
DI1 - Sardinia Strait	.0	1.0	.0	.5	0	0.5	0	0.5
DT1 - NW Tyrrhenian	.0	1.0	.0	.5	0	0.5	0	0.2
DT2 - NE Tyrrhenian	.0	1.0	.0	.5	0	0.5	0	0.2
DT3 - S Tyrrhenian	.0	1.0	.0	.5	0	0.5	0	0.2
DF3 - W Ligurian	.0	3.0	.0	.5	0	1	0	0.5
DF4 - E Ligurian	.0	1.0	.0	.5	0	1	0	0.5
	Total Nitrogen (mmole/m³)				**Total Phosphorus (mmole/m³)**			
DJ1 - North Adriatic	4	15	/	/	.0	1.5	/	/
DJ2 - Middle Adriatic	4	15	6	15	.0	1.0	.0	1.0
DJ3 - S Adriatic	4	30	6	30	.0	1.0	.0	1.0
DJ4 - NE Ionian	4	20	6	20	.0	1.5	.0	1.0
DJ5 - S Ionian	4	20	6	20	.0	1.0	.0	1.0
DJ6 - NW Ionian	4	20	6	20	.0	1.0	.0	1.0
DJ7 - Middle Ionian	4	20	6	20	.0	1.0	.0	1.0
DI3 - Sicily Strait	4	9	6	12	.0	1.0	.0	1.0
DI1 - Sardinia Strait	4	9	6	12	.0	1.0	.0	1.0
DT1 - NW Tyrrhenian	4	9	6	9	.0	1.0	.0	1.0
DT2 - NE Tyrrhenian	4	9	6	9	.0	1.0	.0	1.0
DT3 - S Tyrrhenian	4	9	6	9	.0	1.0	.0	1.0
DF3 - W Ligurian	4	7	6	9	.0	1.0	.0	1.0
DF4 - E Ligurian	4	7	6	9	.0	1.0	.0	1.0
	pH Concentration (pH)							
DJ1 - North Adriatic	6.0	9.0	/	/				
DJ2 - Middle Adriatic	7.0	9.0	7.0	9.0				
DJ3 - S Adriatic	7.0	9.0	7.0	9.0				
DJ4 - NE Ionian	7.5	9.0	7.5	9.0				
DJ5 - S Ionian	7.5	9.0	7.5	9.0				
DJ6 - NW Ionian	7.5	9.0	7.5	9.0				
DJ7 - Middle Ionian	7.5	9.0	7.5	9.0				
DI3 - Sicily Strait	7.5	9.0	7.5	9.0				
DI1 - Sardinia Strait	7.5	9.0	7.5	9.0				
DT1 - NW Tyrrhenian	7.5	9.0	7.5	9.0				
DT2 - NE Tyrrhenian	7.5	9.0	7.5	9.0				
DT3 - S Tyrrhenian	7.5	9.0	7.5	9.0				
DF3 - W Ligurian	7.5	9.0	7.5	9.0				
DF4 - E Ligurian	7.5	9.0	7.5	9.0				

Table 4 - Minimum and maximum control values for the two layers (0-200 m, 201-bottom) in the Central Mediterranean regions as used for the broad-range check of biological and chemical parameters.

Table 5 - Statistical results after the MEDAR/MEDATLAS II validation procedure in the Central Mediterranean regions.

	Quality flags statistics				
	Samples	**QC flag 1,2**	**QC flag 4**	**QC flag 3**	**QC flag 2**
Temperature	241.572	239.880 (99.3 %)	234	1.458	749
Salinity	172.957	170.568 (98.6 %)	886	1.503	440
Dissolved Oxygen	109.510	109.059 (99.6 %)	213	238	736
Nitrate	38.627	37.446 (96.9 %)	993	188	2.246
Phosphate	49.713	49.419 (99.4 %)	244	50	1.831
Silicate	36.094	35.042 (97.1 %)	612	339	1.383
Alkalinity	6.503	6.320 (97.2 %)	111	72	0
Ammonium	20.416	20.025 (98.1 %)	20	371	0
Chlorophyll-a	10.879	10.764 (98.9 %)	31	79	0
Nitrite	30.441	30.538 (99.7 %)	60	23	0
Total Nitrogen	167	89 (53.3 %)	75	3	0
Total Phosphorus	7.410	7.358 (99.3 %)	52	0	0
PH	29.002	28.879 (99.6 %)	63	60	0

values able to distinguish variations due the presence of the highly ventilated bottom waters in the deepest portion of the ocean. The broad-range values along the vertical, introduced here, have minimized the presence of non-representative observations, in particular in the off-shore stations where the inclusion of erroneous data may raise artificial features in the open sea climatological analyses.

From the assembled database, scattered and clearly erroneous measurements (flag 4) were eliminated and the statistical indexes (minimum and maximum values, arithmetical mean and standard deviation, median and quartiles) were computed using data pertinent to each sub-domain and for the three layers, as defined above. Oceanographic measurements are often affected by intrinsically scattered values due to long-term variations, different environmental conditions (regions that include coastal and open-sea areas), different accuracies derived from sampling methods and devices used. Biological and chemical parameters exhibit extremely high standard deviations, that are often larger than the mean values, especially for nutrients. The mean and standard deviations are appropriate descriptors of the distribution of a variable when the variable follows the normal distribution, and this is not necessarily the case for nutrient concentrations. The median and percentile, as non-parametric or parameter-free statistical indexes, represent a better estimate of their variation (Crise *et al*., 2003). Table 6 summarises the parametric and non-parametric statistical indexes computed for the core parameters in the deep layer (800-bottom) using the same subsets of data. The quartile estimates, which represent a measure of data dispersion from the median, are of the same order of magnitude as the standard deviations from the mean. The dispersion of the measurements in the deep layer is, as expected, much reduced compared to that obtained in the upper layers (Tables 3 and 4). For example, the temperature varies from 12.8 to 14.0°C, the salinity from 38.40 to 38.74 and the oxygen from 4.0 to 5.1 ml/l considering both estimates. However, primary nutrient statistical analyses out in evidence standard deviations larger than quartile variations, while they manifest a good agreement for the central indexes (mean and median). One exception occurs in the DI3 sub-domain (Strait of Sicily), where the largest discrepancy between the mean and the median has been observed. This may occur in the case of a low number of samples or large variability; in these circumstances the median and the lower/upper quartiles seem more appropriate to check incoming data. However, these methods should be tested and improved in a future work for data validation. Moreover, the empirical correlation function for multiparametric analyses and the implementation of the Redfield ratios could be a more promising method to increase the confidence levels of data quality control and to validate incoming data especially for those collected with automatic observational systems currently used in operational oceanography.

Table 6 - Statistical indexes (median, 25th and 75th percentiles, mean and standard deviation, sample number) computed in the deep layer (800-bottom) from MEDAR/MEDATLAS II data set in the Central Mediterranean regions.

	Median	25 Per	75 Per	AVG	St.Dev	N.val	Median	25 Per	75 Per	AVG	St.Dev	N.val
	Sea Temperature (°C)						Salinity (pss)					
DJ3	12.97	12.84	13.16	13.01	0.23	975	38.61	38.58	38.67	38.62	0.07	895
DJ4	13.67	13.62	13.73	13.65	0.17	1390	38.7	38.67	38.73	38.7	0.06	748
DJ5	13.66	13.62	13.73	13.68	0.1	1604	38.71	38.68	38.73	38.71	0.04	639
DJ6	13.64	13.6	13.7	13.65	0.09	481	38.7	38.68	38.72	38.7	0.11	204
DJ7	13.7	13.65	13.79	13.74	0.14	4325	38.71	38.67	38.73	38.71	0.07	2266
DI3	13.87	13.79	13.99	13.88	0.12	100	38.73	38.72	38.74	38.74	0.04	81
DI1	13.14	13.02	13.28	13.17	0.17	354	38.47	38.43	38.51	38.47	0.05	269
DT1	13.27	13.19	13.4	13.3	0.14	1117	38.5	38.47	38.55	38.51	0.07	1024
DT2	13.32	13.25	13.52	13.38	0.18	58	38.52	38.49	38.58	38.54	0.08	53
DT3	13.23	13.15	13.36	13.28	0.19	1057	38.49	38.46	38.54	38.51	0.07	755
DF3	13.02	12.98	13.06	13.03	0.08	6986	38.42	38.4	38.44	38.42	0	4771
DF4	13.04	13.01	13.11	13.06	0.08	93	38.42	38.41	38.44	38.44	0.05	70
	Dissolved Oxygen (ml/l)						Nitrate (mmole/m^3)					
DJ3	4.89	4.69	5.11	4.93	0.29	876	4.98	3.98	5.53	4.54	1.45	505
DJ4	4.43	4.3	4.59	4.46	0.27	1174	4.9	4.55	5.14	4.75	0.71	814
DJ5	4.29	4.14	4.42	4.28	0.25	1122	4.98	4.65	5.43	4.9	1.61	297
DJ6	4.41	4.25	4.55	4.4	0.22	200	4.72	4.53	4.98	4.69	0.49	87
DJ7	4.34	4.2	4.49	4.34	0.26	2779	4.83	4.5	5.2	4.82	1.09	1258
DI3	4.23	4.21	4.34	4.26	0.13	78	5.11	4.64	5.48	4.11	2.13	26
DI1	4.3	4.11	4.43	4.28	0.22	173	6.99	6.21	7.57	6.67	1.23	49
DT1	4.32	4.15	4.42	4.29	0.23	428	6.69	5.48	7.5	6.24	1.98	80
DT2	4.06	4	4.36	4.17	0.2	21						
DT3	4.27	4.13	4.37	4.26	0.19	506	6.2	5.08	7.39	6.21	1.67	150
DF3	4.49	4.35	4.6	4.47	0.21	3847	8.1	7.54	8.42	7.87	0.77	627
DF4	4.44	4.4	4.5	4.43	0.11	71						
	Phosphate (mmole/m^3)						Silicate (mmole/m^3)					
DJ3	0.18	0.1	0.23	0.17	0.1	576	8.23	6.24	11.16	8.99	4.2	487
DJ4	0.19	0.16	0.21	0.19	0.06	853	7.74	6.73	8.65	7.58	1.67	807
DJ5	0.17	0.12	0.22	0.19	0.1	457	8.5	7.81	9	8.08	1.53	324
DJ6	0.16	0.12	0.19	0.15	0.05	107	7.67	7.2	8.27	7.71	0.9	89
DJ7	0.18	0.13	0.23	0.19	0.1	1429	8.3	7.42	8.98	7.97	1.51	1273
DI3	0.21	0.16	0.28	0.24	0.12	30	6.49	4	6.78	5.23	2.27	20
DI1	0.32	0.27	0.36	0.32	0.1	62	7.59	6.17	8.31	7.23	1.38	51
DT1	0.37	0.31	0.46	0.39	0.12	123	7.38	5.51	8.93	6.88	2.63	82
DT3	0.31	0.26	0.35	0.31	0.09	198	7.24	5.83	8.4	7.02	1.89	151
DF3	0.38	0.34	0.43	0.39	0.09	1436	7.9	7.3	8.7	7.9	1.06	424
DF4	0.39	0.31	0.52	0.43	0.1	7						

Table 6 - *continued*.

	Median	25 Per	75 Per	AVG	St.Dev	N.val	Median	25 Per	75 Per	AVG	St.Dev	N.val
	Alkalinity (mmole/m^3)						Ammonium (mmole/m^3)					
DJ3	2656	2655	2663	2656	17	5	0.17	0.04	0.53	0.49	0.84	376
DJ4							0.09	0.02	0.26	0.3	0.6	186
DJ5	2712	2546	2720	2666	83	38	0.05	0.02	0.2	0.12	0.12	20
DJ6							0.09	0	0.21	0.15	0.16	40
DJ7	2712	2705	2770	2729	30	22	0.11	0.03	0.24	0.17	0.17	219
DI3	2750	2730	2770	2746	33	8						
DT3	2730	2730	2730	2730	0	1						
DF3	2680	2670	2700	2688	19	35						
	Chlorophyll-a (mg/m^3)						Total Nitrogen (mmole/m^3)					
DJ3	0.19	0	0.26	0.22	0.16	4	11.02	7.48	13.42	11.47	2.55	4
DJ4	0	0	0.01	0.02	0.04	10	9.94	9.37	10.12	10.47	1.17	4
DJ6	0	0	0.01	0	0	2						
	Nitrite (mmole/m^3)						pH Concentration (pH)					
DJ3	0.02	0.01	0.04	0.03	0.05	461	8.21	8.15	8.35	8.24	0.13	70
DJ4	0.02	0.01	0.03	0.02	0.03	735	8.22	8.16	8.26	8.21	0.1	83
DJ5	0.03	0.02	0.06	0.05	0.06	79	8.21	8.15	8.29	8.2	0.1	237
DJ6	0.02	0	0.03	0.02	0.02	44	8.16	8.16	8.16	8.16	0	16
DJ7	0.03	0.01	0.05	0.04	0.03	583	8.15	8.05	8.24	8.14	0.11	216
DI3	0	0	0.02	0.02	0.03	16	8.27	8	8.28	8.19	0.14	9
DI1	0.11	0.08	0.14	0.11	0.03	3	8.1	8.05	8.15	8.14	0.11	16
DT1	0.04	0.03	0.08	0.05	0.03	15	8.03	8	8.14	8.08	0.13	26
DT3	0.04	0.04	0.08	0.06	0.03	6	8.08	8.04	8.19	8.13	0.13	43
DF3	0	0	0.01	0.01	0.03	204	8.17	8.11	8.19	8.15	0.05	964
DF4							8.17	8.14	8.19	8.16	0.04	10
	Total Phosphorus (mmole/m^3)											
DJ3	0.17	0.12	0.22	0.19	0.1	129						
DJ4	0.28	0.22	0.31	0.29	0.1	30						
DJ7	0.21	0.16	0.23	0.22	0.05	8						
DI3	0.26	0.09	0.35	0.24	0.17	11						
DT3	0.35	0.35	0.35	0.35	0	1						

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