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SARDONE
Improving assessment and management of small pelagic species in the Mediterranean

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Project coordinator name: Elisabetta Morello
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Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	**CO**

1. Project execution

SARDONE project was aimed at developing a series of tools which will enable a better understanding, stock assessment and fishery management of small pelagic fish resources (anchovy and sardine) of the Mediterranean. The three major stocks and fisheries i.e. the NW Mediterranean, the Adriatic and the Aegean were chosen (Figure 1).

Figure 1. Map of the SARDONE study areas, corresponding to the 3 major small pelagic stocks and fisheries in the Mediterranean Sea.

Investigations were aimed at detecting nursery areas, at developing echo-surveys for recruitment strength estimation, at filling the gap in knowledge on the ecology of late larvae and juveniles, at improving the selectivity of current fishing gear, at assessing the impact of fry fisheries on the stocks, at exploring the application of novel stock assessment methodologies to Mediterranean small pelagic stocks.

Table 1.　　　Participant list (CO = Coordinator; CR = Contractor; SCR = subcontractor)

Partic. Role	Partic. N°	Participant name	Participant short name	Country	Date enter	Date exit
CO	1	Consiglio Nazionale delle Ricerche – Istituto di Scienze Marine	CNR - ISMAR	ITALY	1	36
SCR	1 (WP 3)	Istituto Nazionale di Geofisica e Oceanografia	OGS	ITALY	1	36
CR	2	Consejo Superior de Investigaciones Cientificas - Instituto de Ciencias del Mar	CSIC - ICM	SPAIN	1	36
CR	3	Hellenic Centre for Marine Research	HCMR	GREECE	1	36
CR	4	Institut Français de Recherche pour l'Exploitation de la Mer	IFREMER	FRANCE	1	36
CR	5	Fundación AZTI – AZTI Fundazioa	AZTI - Tecnalia	SPAIN	1	36

Six European institutions are involved in SARDONE, as summarised in Table 1. OGS (Istituto Nazionale di Geofisica e Oceanografia, Trieste, Italy) was officially included as a sub-contractor of ISMAR for WP3 after the beginning of the project, its responsible scientist being Dr Valentina Tirelli. In addition, Dr Aniello Russo of UNIVPM (Università Politecnica delle Marche, Ancona, Italy) carried out work on Task 2.2 in the quality of Associate member of ISMAR – CNR. Finally, two external experts were involved in the steering committee of SARDONE: Beatriz Röel from CEFAS (Lowestoft, U.K.) and Pierre Fréon from IRD (Séte, France).

The project was directed towards the improvement of the assessment and management of all major small pelagic stocks in the Mediterranean (NW Mediterranean, Adriatic Sea, Aegean Sea) and had specific, well defined objectives which are described below:

1. Objective 1 (WP 1, task 1 and 2): Characterization of essential habitats for juvenile small pelagic fish in the Mediterranean in relation to oceanographic and topographic characteristics.

This was to be achieved by using available information and methods to define the locations of nursery areas and their relation to specific oceanographic and topographic characteristics in the NW Mediterranean, the Adriatic Sea and the Aegean Sea, i.e., the three basins where the major small pelagic fish stocks occur. To this end, data from past, ongoing and new acoustic surveys were used as indicated in the following box:

Surveys conducted during summer (past and ongoing surveys in the Gulf of Lions, Adriatic and Aegean) were used for the characterization of habitats and mapping of sardine juveniles (sardine spawn during winter in the Mediterranean Sea). These summer surveys were covered by other sources of funding (Data Collection Regulation or National Funding). New experimental were surveys conducted during autumn-winter of 2007, 2008 and 2009 in the three areas and were used for anchovy juveniles (anchovy spawn during summer in the Mediterranean). Table 2 summarises the surveys used within the 36 months of SARDONE and table 3 summarises the SARDONE *ad-hoc* surveys.

The historical oceanographic data set is based on all concurrently measured oceanographic and topographic data collected during the acoustic surveys (e.g., bottom depth, CTD casts, zooplankton standing stocks when available etc) together with remote sensed data (SST and Chl-a). New survey data have included CTD data together with remote sensed data (SST and Chl-a) and *ad hoc* zooplankton sampling (in connection with WP3 activities, ecology and growth of late larvae and juveniles).

Table 2. Echo surveys in Mediterranean that were used for the SARDONE project

Area	Institute	Past surveys & on going surveys	SARDONE surveys
Adriatic Sea	ISMAR	2004-2008	Autumn 2007/Winter 2009
Gulf of Lions	IFREMER	2004-2008	Autumn 2007/Winter 2009
Aegean Sea	HCMR	2004-2008	Autumn 2007/Winter 2009

Table 3.   Summary of the surveys carried out *ad-hoc* for SARDONE over the 36 moths of its duration with an indication of the area, date, survey type, distance covered, the numbers of hauls, the target species categories sampled (AL = anchovy late larvae; AJ = anchovy juveniles; SL = sardine late larvae; SJ = sardone juveniles) and other data obtained (JS = juvenile schools; SC = species composition of catch; LF = length frequency distributions of target species; Z = zooplancton; P = phytoplancton; EP = envrionmental parameters). N/A = not applicable.

Area	Date	Survey type	Linear distance covered (NM)	No. CTD hauls	No. pleagic hauls	Target species sampled	Other data obtained	Partner involved
Aegean Sea	23/07 – 04/08 2007	SARDONE	100	12	14	AL; AJ; SJ	JS; SC; LF; 24 hours for feeding ecology; otoliths for growth; Z; P; EP	HCMR
	29/11 – 13/12 2007	SARDONE	300	52	38	AL; AJ		
	15 – 21/07 2008	SARDONE	100	12		AL; AJ; SJ		
	02 – 16/02 2009	SARDONE	300	52	38	AL; AJ		
S. Adriatic	9 – 16/06 2007	On-going	518	19	14	N/A	JS; SC; LF	CNR – ISMAR OGS
Gulf of Manfredonia (S. Adriatic)	17 – 22/06 2007	SARDONE	162	21	11	AL; AJ	JS; SC; LF; 24 hours for feeding ecology; otoliths for growth; Z; P; EP	
N. & C. Adriatic	19/09 - 06/10 2007	On-going	1399	34	34	N/A	JS; SC; LF; EP	
N. Adriatic (Po river)	29/10 – 09/11 2007	SARDONE	293	46	27	AL; AJ	JS; SC; LF; 24 hours for feeding ecology; otoliths for growth; Z; P; EP	
Gulf of Manfredonia (S. Adriatic)	13 – 19/02 2008	SARDONE	117	25	12	AJ; SL		
N. Adriatic (Po river)	16/02 – 02/03/2009	SARDONE	437	55	20	AJ; SL		
Gulf of Lions	11/07 – 10/08 2007	On-going (PELMED 07)	1473	29	39	AL; AJ; SJ	JS; SC; LF; 24 hours for feeding ecology; otoliths for growth; Z; P; EP	CSIC – ICM IFREMER
	08 – 22/12 2007	JUVALION 07	783	22	18	AL; AJ; SJ		
	08 – 14/03 2008	SARDONE	N/A	13	36	AJ; SL	SC; LF; 24 hours for feeding ecology; otoliths for growth; Z; P; EP	
	08 – 29/01/2009	SARDONE	1188	31	35	AL; AJ; SL		

Acoustic data collected from past and on-going surveys were thus compiled, evaluated, summarized, and gaps in data were identified. These data were also re-processed to extract information on sardine and anchovy juveniles. Specifically data were re-processed in order to estimate the location (i.e. coordinates) of juvenile presence and to obtain respective abundance indices at each position. According to the common protocol agreed, the EDSU was set at 1 NM. Following is a summary of the results obtained for the three areas:

Aegean Sea. Based on the re-analysis of acoustic data of past surveys held in Aegean Sea (June 2004-2008), maps of the spatial distribution and abundance indices of sardine juveniles were obtained. High inter-annual variability was observed regarding both the spatial distribution of sardine juveniles a) presence and b) echo-abundance. However, there were certain areas with consistent presence of juvenile sardine between years. In Thracian Sea, sardine juveniles were consistently found in association with the Nestos river outflow and to a lesser extend in the inner part of Strymonikos gulf. Schools of sardine juveniles were mainly located inshore and within the 50m isobath, often associated with rivers' outflows as well as the most productive shallow waters of enclosed areas as in the case of North and South Evoikos gulfs. No juveniles of anchovy were identified in the framework of past surveys in Aegean Sea as they were held during June, which coincides with the peak of the reproduction period of anchovy.

Adriatic Sea. Based on the re-analysis of acoustic data of past surveys held in the Adriatic Sea (September 2004-2008), maps of the spatial distribution and abundance indices of anchovy juveniles were estimated showing that the main anchovy juvenile grounds in the Northern Adriatic Sea were located in the gulf of Trieste, at the Po river mouth and along the Marche coastal area. The North-Western Adriatic Sea is mainly characterized by shallow waters and strong river inputs and high abundances of anchovy juveniles were located in shallow waters except in the southern area of Marche region (off the Tronto river) in which they were found until the 100m depth. In the South-Western Adriatic Sea greater depths are observed and the effect of rivers seems to be less important. However the general circulation in the Adriatic Sea can transport the north river inputs southwards. In this region anchovy juveniles were found in the majority of the areas shallower than 50m depth, reaching deeper waters only in a few zones. Sardine juveniles were found only in September 2005 in proximity of the Trieste Gulf in the Northern Adriatic Sea and around Gargano Promontory in the South-Western Adriatic Sea (in waters less than 100m depth) and near the Gargano Promontory in September 2006. Limited presence of anchovy juveniles was also found in the South Adriatic surveys that took place during July 2008.

Gulf of Lions. Based on the re-analysis of acoustic data of past surveys held in Gulf of Lions (July 2004-2008) maps of the spatial distribution and abundance indices of sardine juveniles were estimated. According to these results, sardine juveniles were consistently present in shallow waters during summer, along the entire coast and especially found near Rhône river estuary, but decreasing from 2004 to 2008. In addition the juveniles of anchovy were very rarely observed during the summer surveys in the area.

A common database, the SARDONE Viewer, containing all previous, ongoing, and new acoustic and environmental/topographic data was constructed and consisted in one of the milestones of the project (Figure 2). The SARDONE Viewer is a customization of an ArcInfo workstation GIS environment developed in Arc Macro Language (AML). It features a user-interface to environmental satellite data used during the SARDONE Project. The user-interface provides information on Essential Fish Habitats (EFH), SARDONE approach to EFH mapping and project participants. The available environmental satellite data that can be accessed through the SARDONE Viewer include AVHRR sea surface temperature (SST), SeaWiFS sea surface chlorophyll-a (Chl-a), modeled sea surface salinity (SAL), merged-satellite mean sea level anomaly (SLA), SeaWiFS photosynthetically active radiation (PAR) and ETOPO bathymetry, all covering the Mediterranean and Black seas. In addition, the SARDONE Viewer includes point surveyed acoustic information from the North/Central Aegean, the Adriatic Sea, and the Gulf of Lions.

A review of the previous knowledge of nursery areas from past surveys was foreseen after 12 months from the start of the project. Data was then assembled and prepared for common analysis within a GIS environment. The distribution and abundance of juvenile fish was modelled using general additive models, which were used in order to define the set of the environmental parameters that describe areas with sardine/anchovy juveniles' presence. Comparison among areas and years was be performed as well as an in-depth exploration of the potential for predicting

nursery areas in terms of biotic and abiotic variables (especially easily collected and inexpensive, such as satellite derived variables). Thus, in order to characterize the habitat of anchovy and sardine juveniles in the Mediterranean, acoustic surveys data along with satellite environmental data were used initially in respect to the presence/absence (occurrence of juveniles) data in order to obtain information and map those potential habitat areas with higher probabilities of having suitable environmental conditions for sardine/anchovy juveniles' presence. In a subsequent step acoustic data were used in respect to echo abundance or biomass estimates (whatever available) in order to determine and map those potential areas with the suitable environmental conditions for high abundances of sardine/anchovy juveniles. Finally the best models with were used (in a predictive mode) to search through the mean monthly satellite values the entire Mediterranean basin, in order to identify areas with suitable environmental conditions associated with a specific probability of juveniles presence, producing presence/absence probability maps (exemplified in Figure 3).

Figure 2. Screen view of SARDONE viewer, a common database containing all previous, ongoing, and new acoustic and environmental/topographic data

In a future perspective the persistency of these potential areas with suitable environmental conditions corresponding to high probability of anchovy or sardine juveniles should be evaluated. Moreover the coupling of potential nursery areas, suitable for both anchovy and sardine should be examined. The areas that present a high inter-annual persistency for each species, as well as the potential areas that are suitable for both species could be the most important for the juvenile from a management point of view.

Finally, in situ CTD measurements were used along with a. presence/absence data and b. abundance data of juveniles in order to have a better understanding of the environmental conditions that affect the spatial distribution of the juveniles at sea. Statistical modelling (GAMs) was used for this purpose. Results indicated the importance of bathymetry and the salinity in the Upper Mixed Layer for the distribution of sardine juveniles. Bathymetry along with temperature and salinity in the UML were important factors, driving anchovy juveniles distribution in September. In late autumn (November-December) and winter (January-February) the environmental parameters in the Bottom Layer were found important. Bathymetry, temperature and productivity were found important concerning the distribution of juveniles in late autumn, with temperature and productivity driving their high abundances. Similarly, during the winter period bathymetry along with temperature were found important for the distribution of anchovy juveniles whereas temperature and productivity were driving their high abundances.
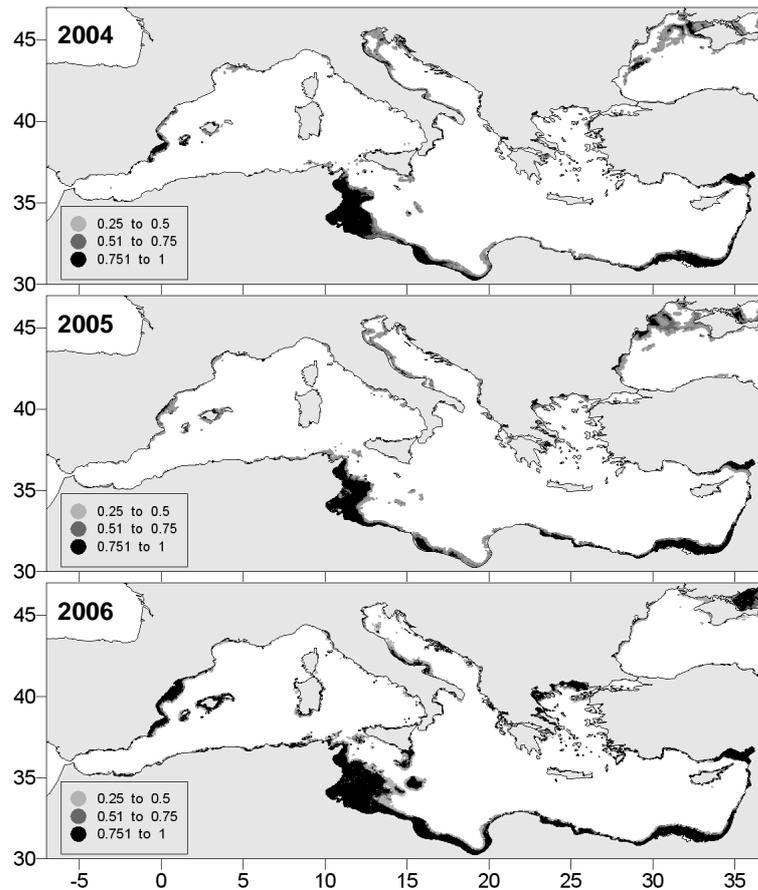
Figure 3. Map of the probability for anchovy juveniles potential presence in the Mediterranean Sea, based on GAM model from the Adriatic Sea during September. GIS resolution used for prediction was 4 km of mean monthly satellite values from September 2004 - 2006. The scale indicates probability ranges.

2. Objective 2 (WP 1, Task 3): Advancement and harmonization of acoustic methods for the estimation of the abundance of juvenile fish as a means of predicting recruitment and improving adaptive management of the stocks.

To improve and harmonize acoustic methods for the assessment of the yearly recruitment of small pelagic stocks in the Mediterranean, is a methodological task which was be performed through two workshops. The first workshop took place soon after the start of the project during the kick off meeting (Ancona, 07-09/03/2007) and methods used for the acoustic surveys as well as the Essential Fish Habitats (EFH) analysis were be presented, discussed and evaluated. In this same meeting, the common format needed for the analysis as well as the design, exact location/times and the standardized methodology for the anchovy autumn/winter surveys was be decided and adopted, based on available information. The conclusions of this first workshop were used in the first coordination meeting of MEDIAS (MEDIterranean Acoustic Survey), held in Athens, where a common protocol for all acoustic surveys was agreed upon. This protocol was followed in all ongoing and SARDONE surveys. A second workshop was carried out near the end of the project and focused on the outcome of the acoustic sampling, with the main aim of advancing and harmonizing juvenile surveys, as a means of estimating year-class strength of pelagic stocks in the Mediterranean. In addition during this second workshop a protocol was agreed targeting the harmonization of the juveniles' surveys; this, again as based on the MEDIAS protocol.

3. Objective 3 (WP 2, Tasks 1, 2, 3; WP5 Task 2): Assessment of the effects of fisheries on post-larval stages on the dynamics of the stocks.

(a) *Assembling and summarizing all available data on these fisheries* (WP2, Task 3)

A study of Mediterranean fry fisheries was thus conducted with the aim of assembling and summarizing all available data on these fisheries; the ultimate scope being that of testing various population dynamics tools with respect to their capability of assessing the impact of fry fisheries on the dynamics of the stocks (Task 5.2).

According to Art. 15, paragraph 3 of Council Regulation (EC) No 1967/2006 of 21 December 2006 "Concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea, amending Regulation (EEC) No 2847/93 and repealing Regulation (EC) No 1626/94" the application of a minimum landing size to marine organisms fished commercially does not "...apply to fries of sardine landed for human consumption if caught by boat seines or shore seines and authorised in accordance with national provisions established in a management plan as referred to in Article 19, provided that the stock of sardine concerned is within safe biological limits.". This means that the sole fry fishery legally authorised by the European Union, under a specific authorisation framework, is that for sardine, *Sardina pilchardus*. Within the areas of interest of the SARDONE project (namely, the Catalan Sea, the Gulf of Lions, the Adriatic Sea and the Aegean sea), commercial, "authorised", sardine fry fisheries occur in only two rather restricted zones: in the French Côte D'Azur between Marseille and Menton (the poutine fishery) and in the Gulf of Manfredonia (Adriatic Sea, Italy – the *bianchetto* fishery).

Data regarding the poutine fishery were very restricted in time and space and limited to those included an IDEE – CREOCEAN – OCEANIC DEVELOPPEMENT done for the "Comité Régional des Pêches Maritimes et des Elevages Marins de la région "Provence – Alpes – Côte d'Azur". These data regarded:

- The fleet: number of operative units (beach seines);
- The gear: mesh size of cod-end;
- The fishing period: number of fishing days per year;
- Production: yearly catches and yearly catches per unit;
- Species composition of catch: qualitative.

The *bianchetto* (Figure 4) fishery is carried out along most of the Italian coast with gears differing from area to area. This fishery is authorised by the EC and legislated by a series of National Ministerial Decrees. Manfredonia (south-western Adriatic) has, by far, the highest number of authorised boats in Italy, accounting for an average 33% of all licences released. Here, contrarily to other areas where sardine fry is fished by means of seines, the fishery is a trawl fishery which makes use of a net with 2 cod-ends, the innermost one with larger mesh sizes (15 mm stretch) and the outermost with very fine meshes (5 mm stretch).

Figure 4. *Bianchetto*, *Sardina pilchardus* post-larvae.

Following a data-mining period at the start of the project a vast amount of information was obtained on the fishery, as follows:

1.   Anecdotal information obtained from the fishermen;
2.   Official landings of the *bianchetto* fishery in Manfredonia from the wholesale market: this included monthly landings from 1996 to 2009 and daily landings for the period 2006 - 2009;
3.   Information on the manfredonia fleet in terms of number of boats operating and number of licenses released yearly (2001 – 2008).
4.   Experimental data:

    (i)   Rizzoli, 1982: These data were collected in the winter of 1982 in Manfredonia and concern a series of 30 minute experimental hauls carried out with the same pelagic trawl used by commercial fishermen during the commercial fishing season. Information available includes species composition in the external cod-end, abundance and biomass of bianchetto, and length-frequency distribution of *bianchetto*;

    (ii)   SARDONE cruise, Gulf of Manfredonia, February 2008. The gear used was an experimental pelagic trawl ("SARDONET") composed of one cod-end with mesh size very similar to the external cod-end used in the commercial fishery. The data available overall include length frequency distributions of *bianchetto* with the corresponding age-length and length-weight relationships.

It is evident that the data available for the *bianchett*o fishery in Manfredonia was more detailed than that available for the *poutine* fishery in France. Despite the overall paucity of information, it was clear that the *poutine* fishery is very restricted both temporally and spatially, operating for a maximum of 45 days per year, along a mere 200 km of coast and within 200 m (20 m depth) of the shore. Furthermore, it constitutes a traditional, ancient, fishery operated mostly by hand by few men whose average age is quite high. It is our opinion from the data available, both scientific and anecdotal, that the impact of the *poutine* (and the associated *poutine-friture*) fishery in the County of Nice, is very unlikely to have any relevant impact on the stock of adult sardine in the Gulf of Lions. Furthermore the available data were deemed to be too scarce to yield any significant results when analysed in the context of the adult stock assessment estimates. For these reasons the *poutine* fishery was not the object of further investigations.

These data served as a starting point for the discussion of possible methodologies to be used in task 5.2 Assessing the impact on the stocks of fisheries specifically targeting late larvae and juveniles (see point (d) below). The (egg) transport mechanisms allowing the two fisheries to exist should be further investigated. In view of the multinational, shared, nature of small pelagic fish stocks in the Adriatic Sea particular attention should be paid to the study of egg transport to and from the Gulf of Manfredonia (see point (c) below): do the fry, when over 50 mm, migrate to deeper waters, eventually becoming the adults found on the eastern side of the Adriatic, or, *vice versa*, do they arrive from the eastern side of the Adriatic?

(b)   *Developing and testing a suitable monitoring tool, based on available acoustic and fishing gear technologies to sample these early life history stages* (WP2, Task 1)

Work towards the development and testing of a suitable monitoring tool, based on available acoustic and fishing gear technologies to sample these early life history stages was done in the Adriatic where the presence of traditional fry fisheries allowed the straightforward selection of the area of investigation. Within the framework of SARDONE, in the first year, three echosurveys were carried out in 2007 and 2008 on late larval and juvenile stages of anchovy (November 2007, Northern Adriatic Sea) and sardine (June 2007 and February 2007, Southern Adriatic Sea). To estimate the abundance of late larval and juvenile stages, split-beam Simrad EK500 tranducers operating at 38, 120 and 200 kHz were used and towed at a depth of about 1-2 m in coastal waters (10-50 metres). During these surveys, biological sampling was carried out with the fine-meshed pelagic trawl, SARDONET (cod end mesh size 5 mm, horizontal net opening = 3.7 m, vertical net opening = 2.1 m) (please refer to Deliverable 1). Data obtained from these specific post-larval and juvenile surveys were used to further refine the multifrequency methodology in order to discriminate juveniles from adult fish of the same species. Monospecific hauls for anchovy and sardine late-larvae were selected in order to characterize these small organisms for their acoustic properties which are still poorly known: hauls number 27, 31, 39, 43 and 47 were used (Figure 5).

During routine acoustic surveys in the Adriatic, the difference in mean volume back scattering strength (DMVBS) at two frequencies (120 and 38 kHz) is used to differentiate small pelagic fish with a swim bladder, from other groups of scatterers. The reference interval used is:
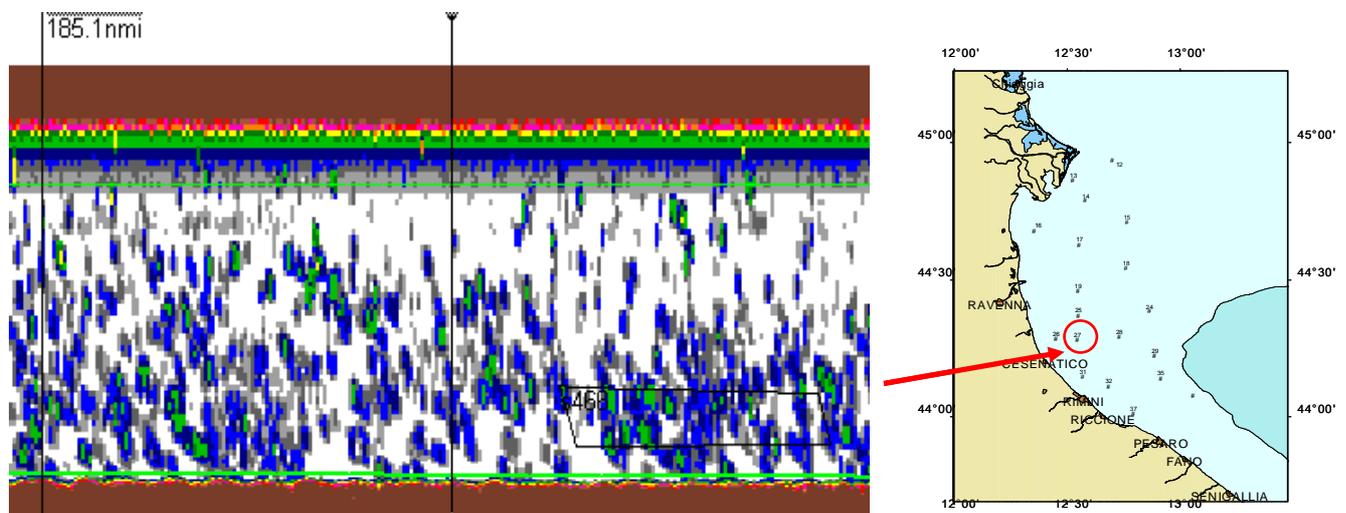-12 dB<10*Log(Sv 120/ Sv 38)<+3 dB

Figure 5. Echogram and geographical position of haul 27

Frequency comparisons on these hauls indicated an acoustic behaviour in anchovy and sardine post-larvae similar to that of adults; the role of the swim bladder is thus not negligible. Echoes from these post-larvae received at 38 kHz were quite weak (mean around -70 dB). Following the approach of Myashita (2003) for *Engaulis japonicus* larvae, the acoustic behaviour of late-larvae was verified further by testing if the Fish Bladder Resonance Model (model suited for fish with swim bladder) would match with the target strengths recorded in the catch stratum. The correspondence of measured Target Strengths in the haul stratum and Target Strengths obtained from the conversion of measured sizes of biological samples through the Fish Bladder Resonance Model was quite good, at least at 38 and 120 kHz; fact which appears to confirm an active role of the swim bladder in anchovy and sardine late-larvae. Even if acoustic characteristics of small pelagic fish larvae are far from being fully understood, specific surveys, such those experimented during SARDONE, showed the potential to be a good tool to start collecting useful information. Further work will bring to the definition of a proper methodology to perform larvae biomass estimation.

(c)   *Characterizing late-larval habitats in relation to topographic and oceanographic conditions through the development of a tool simulating the advection of eggs, larvae and late larvae from spawning areas using hydrodynamic models* (WP2, Task 2)

This point, linking occurrence of concentration of late larvae to oceanographic processes (described by 3d oceanographic models) in the region is crucial for the future development of forecasting tools aimed at improving the fishery management of these resources.
In the north-western Mediterranean, recent studies have indicated that there is a significant net transport of anchovy larvae southwards from spawning areas associated with river run-offs (i.e., in the Gulf of Lions), with the advection of continental waters by permanent currents in the area. Hence, hydrological factors may have a strong effect on the establishment of nursery areas. In this project, 3D hydrodynamic models were combined with available data on spawners and eggs and larval distributions with the aim of modelling the drift of anchovy eggs and larvae in the Mediterranean.
Lagrangian tools in numerical modelling are increasingly used in fisheries to estimate the transportation and the dispersion of eggs and larvae by currents. Such numerical Lagrangian approaches are common in very productive area (upwelling studies) but more rare in Mediterranean Coastal Sea. Simulating the advection and the dispersion of eggs and larvae may

support the interpretation of recruitment survey data and may help to understand the variability of the stock of small pelagics (Anchovy and Sardine) in a particular area. Hydrodynamical modelling is now mature in the Mediterranean Sea and the main features of the circulation are (at least statistically) well reproduced. The availability of numerical modelling now allows the explorations of the potential of the Lagrangian approach. Furthermore, one would expect that the operational oceanography will provide a complementary tool for fisheries management.

IFREMER proposed the use of a common Individual Based Model (IBM) lagrangian tool for the simulation of egg and larval drift, ICHTHYOP (developed by IRD, supported by IFREMER). The purpose of ICHTHYOP is that of simulating particle transport using 2D or 3D oceanographic fields produced by hydrodynamic models such as ROMS or MARS; and to study how physical factors (e.g., currents, water temperature) and biological factors (e.g., egg buoyancy, larval growth) affect the dynamics of fish eggs and larvae. During SARDONE several upgrades of ICHTHYOP were proposed and implemented by the partners (and included in the current version of the software):

- adaptation of the inputs for the model of the Adriatic Sea (IFREMER)
- modification of the diurnal vertical migration (IFREMER)
- introduction of time varying eggs density (instead constant) (ICM)
- Direct effect of the wind forcing for eggs or larvae near the surface (IFREMER)

HCMR used its own lagrangian tool already included in the numerical hydrodynamical model of the Aegean Sea.

Following is a summary of the methods used and results obtained for each area:

Adriatic Sea. The work in the Adriatic Sea regarded both anchovy and sardine. The basic hydrodynamic model used for the Adriatic sea was he 3D, free surface ROMS hydrodynamic model which was run in two configurations: (i) a curvilinear grid with horizontal resolution varying from 3 km in the north to 12 in the southern end of the basin (Otranto Strait), and (ii) a regular grid with uniform 2 km resolution. Both model configurations run including also an NPZD biogeochemical flux module. By performing a series of monthly simulations, with eggs released every 3 days, covering the whole year for 2004 and 2006, general information regarding possible concentration and retentions areas was obtained. *Ad-hoc* database and GIS tools were developed to allow deeper analysis of the Ichthyop outputs. This allowed to obtain information about recruitment of eggs released in areas and periods typical of anchovy and sardine respective spawning. Finally, specific "backward" Ichthyop simulations driven by larval age sampled during the SARDONE cruises in the Gulf of Manfredonia gave further insights into the dynamics of this area where a relevant sardine fry fishery takes place.

General results for anchovy indicate that the circulation patterns concentrate larvae along the western coast, while the whole eastern area is characterized by sensibly lower recruitment percentage. Analysis of the number of days spent by larvae in different areas indicates that this is less in the western sector, being below 10 days (except for the northernmost part of the basin north of the Po River delta); this indicates that larvae reaching the most favourable areas for recruitment (south of Po River delta for anchovy and in Gulf of Manfredonia for sardine) could be transported away before they recruit. Looking at fate of eggs released in the typical anchovy spawning areas, a good number of larvae (above 20%) is recruited in the favourable areas during the warm season. Analysing the outputs in a reverse mode, i.e. searching from where larvae recruited in the favourable zone were spawned, most of them were released in the offshore western and eastern areas of the northern Adriatic basin. The same analysis performed for sardine indicates that spawning in the cold season reaches mostly the western areas of northern and central Adriatic. In the Gulf of Manfredonia (southern Adriatic), recruitment of sardine larvae reaches percentages above 10% only in December and January (the two months immediately preceding the fry fishery season). The reverse analysis says that recruits in the Gulf of Manfredonia were released in the offshore western and eastern areas of a wider central Adriatic), including the known spawning areas and in particular the Meso-Adriatic Depressions ones.

Aegean Sea. In order to investigate the trajectories of the anchovy eggs, the output of a 3D hydrodynamic model (10 kilometres resolution model based on the POM code coupled with a surface wave model (WAM) and biogeochemical model (ERSEM)) was coupled to a particle-tracking model. Results from the model indicate that spawning area, egg mortality and spawning frequency have a major effects on transport success. Simulations were performed in June - July (peak of spawning) and in general, there was good agreement between observed patterns and the

optimal temporal and spatial strata, suggesting that the spawning strategy of anchovy is mainly the result of an adaptation to the circulation patterns in the region. Sensitivity experiments were performed, taking into account the effect of surface waves drift or the frequency of spawning.

Gulf of Lions. The work in the Gulf of Lions regarded anchovy only Seven years of an eddy resolving model were performed using the Ifremer MARS3D code. The Ichthyop software was used (and modified) to derive lagrangian trajectories of eggs and larvae. The strategy used consisted in a weekly spawning in the Gulf of Lions from mid May to mid August. Eggs were assumed to uniformly distribut themselves on the shelf and the final recruitment was assumed when larvae reached 30 days of age. Two numerical experiments were conducted (Figure 6 exemplifies results):

0. assuming passive transportation at a constant depth of 15 m; and
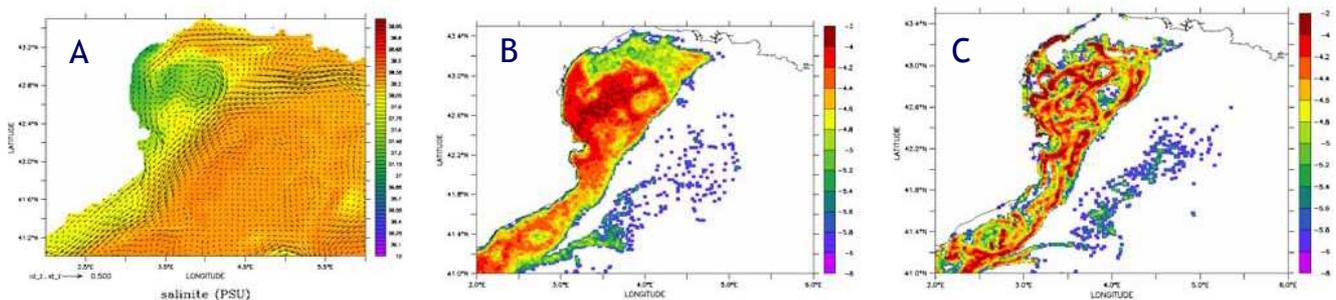1. assuming diel vertical migration at 7 days of age.

Figure 6. A. Currents and salinity at 15 m depth averaged between 16 and 23 June; B. Particle concentration (logarithmic scale) after 30 days for passive transport, C. Particle concentration after 30 days for diel vertical migration. The spawning date is 22 May 2006 (modified from Nicolle et al., 2009).

Despite a large connection with the open sea, the Gulf of Lions (GL) remains a relatively closed area as regards the lagrangian exchange. The results of the MARS-3D model show high hydrodynamic variability strongly related to wind action. Lagrangian simulations showed that, although circulation in the GL is strongly linked to the wind, particle retention appears to be independent of atmospheric forcing. The main effect of diel vertical migration was the concentration of 30-day-old anchovy larvae in areas of lower salinity. Residence time was enough for larvae to stay in the Gulf for 40 days on average. This would mean that the early stages of anchovy would be in the appropriate conditions to survive according to Bakun's triad. The Gulf of Lions combines 3 fundamental processes: enrichment by land inputs of the Rhone and other smaller rivers, concentration in favourable areas by wind and buoyancy-driven circulation and overall retention on the shelf due to the Northern Current barrier.

d) *Testing various population dynamic tools with respect to their capability in assessing the impact of fry fisheries on the dynamics of the stocks* (WP5, Task 2)

The final intention of this objective was that of performing a stock assessment including the juvenile catch and exploring sensitivity of the results obtained to the uncertainty in the data. Analyses were concentrated on the Manfredonia *bianchetto* (sardine larvae) fishery, based on the data collected for WP2 task 3 (see point(a) above). Data used included the following:

* Commercial data from the Manfredonia fish market;
* Length – frequency distributions and growth data from WP3 of the SARDONE project;
* Abundance from Adult stock assessment: Age 1 estimates from Laurec Shepherd tuned VPA and, to explore the sensitivity of the results to stock size, from ICA;

Prior to the assessment, an extensive review of the literature on natural mortality (M) for sardine and anchovy late larvae was carried out to identify models of larval mortality we could use: four possible models were chosen: (i) Pepin (1991): based on growth rate and length, (ii) Jung et al. (2008) based on length, (iii) McGurk (1987) based on weight: two functions were predicted by McGurk (1987), one for juveniles (J) and one for eggs and larvae (EL) and both were tested in these trials, and (iv) an empirical Pareto function modified to take into account known (from

literature) values of initial and final (Age 1, in this case) natural mortality estimates. Different *bianchetto* catch scenarios (official catches and official catches *5) as well as different stock size scenarios were tested along with the different natural mortality functions. For each combination of scenario and natural mortality function, 2 assessments were carried out:

1.   Assessment of the impact of the *bianchetto* fishery on recruitment levels (at age 1)

This a cohort by cohort assessment of the impact of the *bianchetto* catches relative to the official assessment of stock size (of the recruitment at age 1). It was carried out in a stepwise fashion as follows:

   (a) Starting from the youngest survivors of the adult assessment: the abundance of Age 1 individuals (numbers) resulting from the VPA was used (see objective 6 below);
   (b) These were projected backwards for 12 months including *bianchetto* catches (in numbers) and assuming the different M and growth patterns described previously;
   (c) Age 1 individuals from the VPA were projected forwards assuming the same M and growth patterns assumed for step 2 but without *bianchetto* catches; and
   (d) The impact of the catches on the projected population was assessed in terms of % difference;
   (e) The sensitivity of the results to the actual level of the population (or simply of recruitment at age 1) was evaluated using the outputs from the ICA alternative assessment (see objective 6 below) as a natural alternative scenario of the actual stock size of the sardine population.

2.   Assessment of the impact of the Manfredonia *bianchetto* catches on the Yield per recruit of the fishery

Again, this assessment was carried out in a stepwise manner, as follows:

   (a) A constant annual M for Age 0 (M0) was calculated by projecting the *bianchetto* catches forward and estimating the survivors at the end of the year, had they not been fished. M0 was calculated from the mean day of the fishery (= average size of the fish caught), which was day 100. So, technically, M0 was calculated from day 101 to day 366. This value was then multiplied by two to obtain a yearly value of M0. We decided to multiply by 2 the cumulated M0 from the mean date of the *bianchetto* fishery to the 1st January of the following year was because in such a manner we accommodated quite well the assumptions upon which VPA is based (Pope's approach to VPA assumes that catches taken at the middle of the year are a good proxy of the result of a continuous F and M acting over the whole year). Still, owing to the exponential decay of the mortality models for the early life stages, this is most likely an underestimation of M0.;
   (b) This was done for just two of the five mortality models chosen: (i) Pepin (1991): this model was chosen owing to the nature of the information included in the calculation of mortality which rendered it the most accurate and suitable when considering the biology of the species and the nature of the fishery; and (ii) McGurk (1984) Juvenile: we decided to use this mortality function rather then the egg and larvae (EL) variant because the EL model gave a constant annual M0 very similar to Pepin (1991) and because the *bianchetto* caught, especially at the end of the fishing season (March – April), is very close to metamorphosis, therefore it made sense to consider this juvenile function as representative of the subsequent mortality till the end of the year.;
   (c) For each M0 estimate a Yield per recruit analysis (Y/R) was performed: one run with *bianchetto* catches and one run without *bianchetto* catches.;
   (d) The Yield per Recruit values obtained from each fishing pattern (with and without *bianchetto*) were be compared at FMult = 1 in order to quantify the impact of the fishery on the stock of adults, according to :
   • Yield per Recruit (Y/R) curves with and without *bianchetto*;
   • Spawning Stock Biomass per Recruit (SSB/R) curves with and without *bianchetto*;
   • Catch of Age 1+ per Recruit (CA1+/R) curves with and without *bianchetto*;
   (e) In addition, to analyse the sensitivity of the results to the choice of M0, the same routine was carried out on a range of arbitrary M0 values, from 1 to 9 in steps of 0.5.

Results showed that the *bianchetto* fishery in the Gulf of Manfredonia impacts the overall adult stocks to variable extents depending, mainly on the natural mortality function used. The use of the

most plausible one (Pepin, 1991) indicated impact levels on the adult stock ranging between 0.3 and 3.7%.

4. Improvement, through a comparative approach, of the understanding of the biotic and abiotic agents that control late-larval/juvenile growth and feeding rates and consequently the recruitment strength.

This objective is based on the study of late-larval and juvenile anchovy and sardine growth and feeding in the NW Mediterranean, the Adriatic Sea and the Aegean Sea within a comparative framework. Appropriate *ad hoc* sampling of fish, phytoplankton, zooplankton and the environmental conditions were conducted during the ongoing and new acoustic surveys of the project (juvenile feeding and growth) and the surveys of late-larval fish in the Adriatic Sea. Additional sampling for late larval stage ecology were made in the Aegean Sea and the western Mediterranean in areas of expected high fish abundance (e.g. river mouth areas) with methods developed in the Adriatic. The comparison of diet, feeding and growth rhythms in contrasting environments of the Mediterranean should highlight the environmental agents that favour the strength of recruitment of small pelagic fish in the Mediterranean. The determination of diet compositions during these stages (which are completely unknown) have the aim of further contribute to the improvement of current ecosystem models (Ecopath/Ecosim) that have been developed for the NW Mediterranean and the Adriatic Sea during recent years. These models require estimates of daily ration and growth rates of the major functional groups in order to describe energy fluxes throughout the ecosystem. Small pelagic species are fundamental components of any ecological model taking into account high trophic levels (i.e., fish and fishery) in the Mediterranean. These models are based on trophic web interactions and enable to quantitatively describe the structure and functioning of exploited marine ecosystems. To detail ontogenetic fractions of key species included in the models (like sardine and anchovy), from an ecological point of view, is one of the most important elements to be developed. This would enable the further understanding of the dynamics of recruitment in an ecosystem context. This objective does not provide a direct link to the issue of immediate fishery management but is aimed at building up the knowledge necessary for more scientifically sound ecological modelling which are being developed.
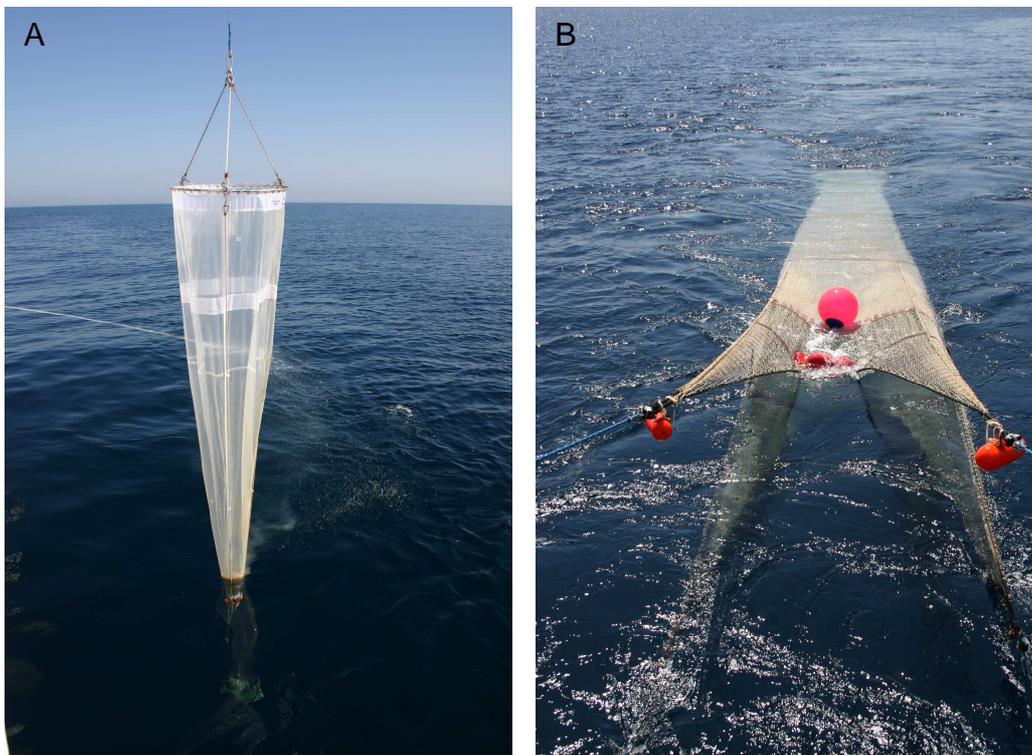
Figure 7. A. Sampling for plankton, B. Sampling for fish larvae and juveniles with SARDONET.

The initial period of the project was mainly devoted towards obtaining data on the environmental parameters and the late larvae and juveniles of both species, anchovy and sardine. Sampling of fish, phytoplankton, zooplankton and the environmental conditions was carried out during the acoustic surveys of the project in the three areas, Aegean Sea, Adriatic Sea and Gulf of Lions (Figure 7). Additional sampling surveys to collect information on the ecology of late larval stages were also carried out (Table 3). Previous to the first cruise carried out, a common standard sampling protocol was decided upon.

Feeding studies

This task was based on the study of late-larval and juvenile anchovy and sardine feeding in the NW Mediterranean, the Adriatic Sea and the Aegean Sea within a comparative framework. Research on ecological topics (e.g. feeding, growth and spawning) is necessary in order to understand the stock and population dynamics of these fishes. Furthermore the determination of diet compositions during these stages (which are completely unknown) will further contribute to the improvement of current ecosystem models that have been developed for the NW Mediterranean and the Adriatic Sea during recent years (Coll et al., 2007; Coll et al., 2008), and are currently being developed for the Aegean Sea. These models require estimates of daily ration of the major functional groups in order to describe energy fluxes throughout the ecosystem. Small pelagic species are fundamental components of any ecological model taking into account high trophic levels (i.e. fish and the fishery) in the Mediterranean. To detail ontogenetic fractions of key species included in the models (like sardine and anchovy), from an ecological point of view, is one of the most important elements to be developed. Another topic of great concern is that regarding the trophic relationships among these fishes, such as prey partitioning and competition. These species inhabit the similar pelagic habitat, hence they have the potential for a similar diet and for trophic competition or the species may show trophic partitioning of their prey items. This would enable us to further understand the dynamics of recruitment in an ecosystem context.

This objective is not providing a direct link to the issue of immediate fishery management but aims at building up knowledge necessary for more scientifically sound ecological modelling which are being developed.

The specific objectives of these studies are: (i) to assess the diet of late larvae and juveniles of sardine and anchovy in the three regions by determining the major dietary components in relation with the environment conditions, and (ii) to provide daily ration estimates as a tool to estimate the zooplankton consumption by the entire population and its impact on the ecosystem. In addition analyses of zooplankton biomass, micro and mesozooplankton, jointly with the environmental parameters obtained from each of the cruises were carried out and related to the information on diet.

A common protocol was established for the collection and analysis of feeding data and was adopted by the research groups participating in WP3. The analysis plankton samples and stomach contents of anchovy and sardine late larvae and juveniles was carried out on all samples obtained from the three regions in the first reporting period and from the new samples obtained in Summer 2008 and Winter 2009 in the Aegean Sea and the Gulf of Lions. This provided important results regarding the trophic ecology of the early ontogenic stages of these species in each of the regions and in three times of the year: summer, winter and autumn.

The data obtained on plankton abundances and composition in the three regions allowed comparisons to be made regarding the trophic environment of the late-larvae and juveniles of anchovy and sardine. The attention was focused on data obtained in the three seasons where possibilities of comparisons between areas were more feasible, e.g. the trophic ecology of anchovy juveniles. Sardine juveniles were only collected and analysed in the Aegean Sea and Gulf of Lions, but further analyses are still needed in order for comparisons between these two regions to be conclusive. Results obtained for the late larvae of both species did not allow comparisons to be made, because, overall, larvae had empty stomachs with the exception of sardine late from the Adriatic.

1.   The plankton community.

Plankton samples were obtained from the three regions in all the seasons, but the abundance of the mesozooplankton and microplankton main groups was analysed for the following situations alone:

(i)   the Adriatic Sea, Aegean Sea and the Gulf of Lions in December 2007 and February-March 2008-09, coinciding with studies on the diet and daily ration of anchovy juveniles;

(ii)   the Aegean Sea and the Gulf of Lions in July coinciding with studies on the diet and daily ration sardine juveniles.

Copepods always represented the bulk of the community in the three areas, with the higher values for the copepod nauplii, present at the microplankton community. Other abundant groups were Cladocerans, Chaetognata and Cnidaria. Among the meroplankton, mollusc larvae were dominant, especially in the Gulf of Lions during summer, probably due to the very coastal position of the sampling areas.

2.   Comparison of diets of anchovy juveniles in the three areas.

The species composition (in terms of abundance of each prey, N•individual-1) of the stomach contents of juvenile anchovy was analysed for differences between areas (A = Adriatic; E = Aegean; L = Gulf of Lions) by means of multivariate non-parametric analysis of variance of linear models, based on distance measures (PERMANOVA; Anderson, 200a) using an unbalanced design, and constrained and unconstrained ordination techniques. These techniques revealed a distinct grouping of samples according to area with the Aegean Sea and the Gulf of Lions being apparently more similar, and the Adriatic overall more dissimilar (Figure 8).
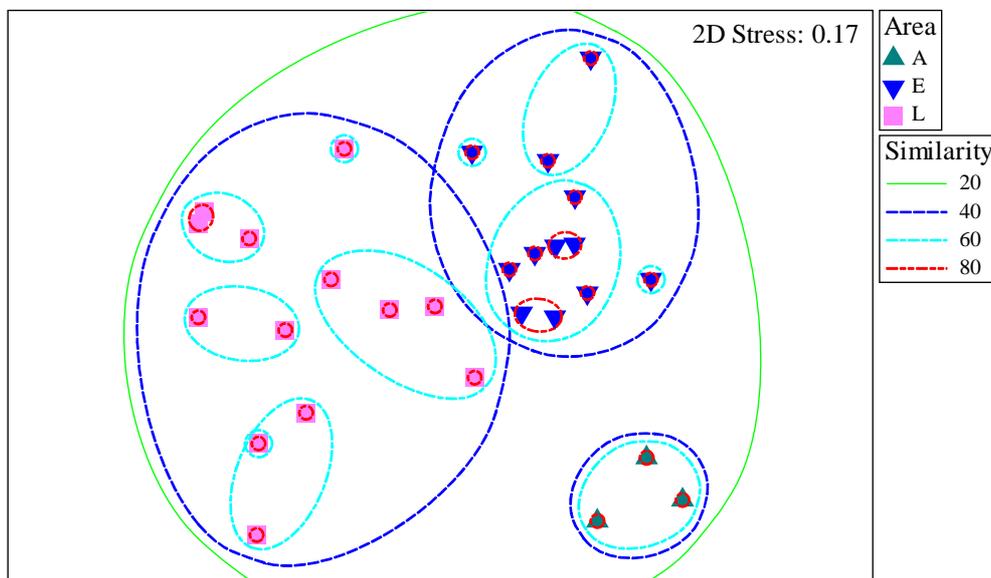

Figure 8. Non-metric MultiDimensionalScaling (nmMDS) analysis carried out to visualise juvenile anchovy diets (species composition and abundance) in the three areas of interest: Adriatic Sea (A), Aegean Sea (E) and Gulf of Lions (L). The nmMDS was performed on Bray-Curtis similarity matrices of standardised, fourth-root transformed abundance (N of prey•individual-1) data. The samples are grouped according to the results obtained from the cluster analysis.

The diets in the three areas were also analysed for differences amongst the three different moments of the feeding cycle: day time, night time and time of maximum stomach fullness. The number of preys was always found to be highest in the Adriatic samples compared to the other two areas. Copepods were always found to be the most dominant prey category but strong differences in the copepod composition in juvenile anchovy diet were observed among areas and periods. In the Aegean samples, Calanoida were always the most abundant group. In the Adriatic samples the dominant copepods were of the genus *Oncaea* at the maximum feeding and at night while during the day Calanoida were also important. Samples from the Gulf of Lions were characterized by important percentages of Harpacticoida copepods, being maximal at night (>85%) while Calanoida copepods increased their presence during the period of maximal feeding.

3.   Daily Ration Comparisons (sardine and anchovy)

This is the first time an analysis of juvenile daily ration (consumption) was carried out for anchovy as well for sardine in the Mediterranean. From the samples obtained in the three regions

comparisons between areas could be made for anchovy in late autumn in the three areas and for sardine in the Aegean Sea and Gulf of Lions.

For anchovy juveniles the highest values of daily ration and evacuation rate (R and C) were obtained in the Aegean Sea in summer; this fact is consistent with the higher temperatures experienced by the fish. Nevertheless, in autumn the evacuation rate was higher in the Adriatic Sea. This result is most likely related to the peculiarity of the diet in this area, rather than to the environmental temperature.

Daily ration results were very similar for anchovy juveniles in the Adriatic and the Aegean Seas, in contrast to the lower values obtained for the Gulf of Lions. This was probably due to the small number of consecutive samples obtained in the latter aera, as it was only possible to sample one entire daily cycle in this area. This fact may also be responsible for the high variability of results obtained in the Gulf of Lions region with the different models applied.

The results obtained for sardine juveniles also reveal higher values in the Aegean Sea compared to the Gulf of Lions, for both daily ration and evacuation rate.

The main results obtained are summarised on an area-by-area basis following:

Adriatic Sea:
- Anchovy juveniles and sardine larvae were exclusively zooplanktivorous, with copepodites and copepods being their principal prey;
- In the Adriatic Sea, the biomass of microplankton exceeded that of the mesozooplankton almost in all the stations. The presence of large amounts of small copepods (copepodites and small species) in the microplankton samples confirmed the validity of the sampling protocol adopted in the project;
- Copepod nauplii, despite their abundance in the environment, were not recovered in the fish gut contents;
- Anchovy juveniles fed mainly on few copepods species: *Oncaea, Clauso-Paracalanidae group, Temora stylifera;*
- Sardine diet was based on the species *Temora longicornis* and other small Calanoids belonging to the families Clausocalanidae and Paracalanidae.
- The different models used to estimate daily ration of anchovy juveniles gave concordant results, within the range 2.2-2.3%.

Aegean Sea:
- Mean mesozooplankton abundance throughout the entire sampling grid (12 stations) did not vary significantly among the four surveys, however, mean biomass was found to be significantly higher during December 2007;
- Mesozooplankton community structure presented a considerable spatial differentiation during all surveys;
- The plankton community did not present any among-survey differences in terms of total biomass and total abundance at the four stations (st. 8-11) adjacent to the trawling area;
- From the samples analysed, some selectivity of post larvae of both species can be hypothesized, but more detailed work on a larger number of samples is required;
- Consumption estimates were highly dependent on the chosen model. However, the daily ration of anchovy juveniles was found to be higher during the summer (July 2007) in comparison to that of juvenile sardines. During the winter a clear feeding pattern could not be detected for anchovy juveniles, so estimates of consumption should be considered with caution;
- The main prey for both anchovy and sardine juveniles in all periods were copepods. A partial dietary overlap, in terms of copepod species ingested, was observed for sardine and anchovy juveniles during July 2007, as *Euterpina acutifronts* and *Oncaea* spp. comprised approximately 40% of the ingested prey items for both species. However, differences in diet were also observed, as anchovy showed strong selection for *Acartia clausi* whereas for sardine the 3rd most abundant prey in stomach contents was *Paracalanus parvus* which was the most abundant copepod species during that period;
- During December 2007 juvenile anchovies showed increased selection towards *Centropages typicus* compared to July 2007 when *A. clausi* was one of the preferred prey items;

Gulf of Lions

- Temperature was significantly higher in both summer 2007 and 2009 compared to winter cruises, but salinity did not show differences among seasons.
- Abundance of mesozooplankton was lower in summer 2007 than in winter 2009, despite of the opposite being true for biomass. This could be due to the presence of Cladocerans during the summer, maybe with a higher body density than copepods.
- The same was found for microplankton, its abundance in March 2008 being much higher than in summer 2007, but its biomass being higher in summer 07 than in any other cruise.
- There were clear differences between coastal and offshore stations regarding the plankton community which was more abundant inshore.
- When putting together anchovy diets from December 2007 and January 2009 no clear pattern could be seen, but the MAXIMS plot showed a peak at 8pm, similar to sardines.
- Consumption results were highly variable within the anchovy juveniles depending on the model used. Consumption rate was higher for sardine juveniles than for anchovies, probably due to the fact that sardine was caught in summer at higher temperatures and anchovy was caught in autumn.
- Anchovy juveniles always selected copepods, mainly calanoids, rather than any other prey type; however, sardine juveniles in summer ate a high percentage of cladocerans and non-calanoids copepods, this could imply no interspecies diet overlap.

Growth studies

The comparative approach required in this project implied agreement by different readers on the interpretation of the otolith microstructure, in order to make any comparison of the growth differences or similarities between regions feasible.

At the beginning of the project, a protocol for the extraction and preparation of the sardine and anchovy otoliths was prepared, and after a series of intercalibration workshops, adopted by all involved participants. The examination of partial results during the final general meeting led to strategy towards the homogenisation of results in order to make them more comparable, taking full advantage of the availability of larvae and juvenile specimens collected. For example, the same age methodology and correction for preservation and handling larvae shrinkage were applied. Unfortunately, sampling was not always successful in collecting enough samples in the same periods for all study areas allowing only few cross area comparisons to be carried out.

The differences in the covered length ranges for anchovy are interesting, showing small larvae in the Adriatic on December 2007. Regarding sardine larvae, the size range sampled in the Gulf of Lions was skewed towards bigger sizes for the same period. These differences might be due to different spawning dates or to sampling bias. The water temperatures were consistently higher in the Aegean Sea, with the greatest difference in summer months. The morphometric and growth by life phases and area for each species were examined by means of ANCOVA models.

The results for the anchovy and sardine larvae in December 2007 in the Gulf of Lions were affected by the small size range sampled, only one anchovy larva being bigger than 32 mm, causing the poor correlation between the parameters determined. The larvae of both species seemed to be in better condition in the Aegean Sea in both seasons, based on the isometric growth (b of the TL-TW relationship) and on the mean daily growth rate in length. However, for juveniles the growth rates seem to be lower in the Aegean Sea. The maximum increment width varied markedly between areas, species and seasons probably due to the plasticity in otolith growth, supported by the high standard deviations of increment measurements in all studied areas. To explore if the differences found between areas were related to environmental parameters, surface water temperature was used as it is an important factor in fish growth and of season signal. The comparison on the otolith increment widths by season and area in relation to the surface water temperature (SST) was performed for sardine and anchovy juveniles grouping the data by year date and week using the same time intervals than the ones used for the SST. Three sardine juvenile groups were present in the three areas due to the prolonged spawning period, which reaches up to 15 weeks. When all the anchovy increment width evolutions with age were considered against the Julian calendar day, a progressive incorporation was noted, depending on the area: the first to appear were the Adriatic fish, followed by the Aegean and finally the Gulf of Lions. The growth rates and maximum growths were different depending on the age group

considered, although the general tendency was from smaller in the Aegean to bigger maximum growth in the Gulf of Lions. The growth rate varied greatly depending on the group considered, although initially the growth rates were more or less similar, consecutive growth was very different depending of the group and area. One group, corresponding to the fish born later in the Aegean, showed the best initial growth rate by week 4, then growth rate decreased sharply. Apparently the start of the decrease in growth rates was size related because it depended on previous growth and not on the age. This is probably related to some life phase event such as the start of the metamorphosis.

The main results obtained are summarised on an area-by-area basis following:

Adriatic Sea

Anchovy Larvae

- The slope for standard length (SL) vs. age was 0.66 mm day^{-1}, in the Po river area in November 2007 and 0.49 mm day^{-1} in the Manfredonia area in June 2007. The growth rate of anchovy individuals caught in November off the Po river mouth, were significantly higher than those collected in June in Gulf of Manfredonia whilst no significant differences were found for growth-in-weight. These results partially disagree with the general pattern observed in another Adriatic site (Ortona, south of PO, north of Manfredonia) where the instantaneous growth rate increased in May (0.82 mm·day^{-1}) and decreased in August (0.54 mm·day^{-1}) and November (0.55 mm·day^{-1});
- Seasonal changes in environmental and trophic conditions largely affected instantaneous growth rate, indicating that the environment (e.g. food availability) was more favourable off the Po river mouth.
- The otolith increment widths for both samples showed trends very similar to those observed in the Aegean Sea. For both periods increment width increased continuously, although for larvae caught in November an onset of increment width decrease was evident close to the end of the curve. This was due to the fact that larger specimens were used in November including metamorphosing specimens (metamorphosis is associated with a decrease in increment width);
- Anchovy larvae caught in June 2007 had slightly wider increments compared to those caught in November 2007.

Sardine Larvae

- The instantaneous growth rate estimated for sardine late larvae (0.23 mm·day^{-1}) was lower than those estimated for anchovy;
- Increment width increased slowly and rather constantly and the maximum values were always lower than 4 µm;
- The growth increments became progressively wider ranging from 1.29 ± 0.20 µm to 2.62 ± 0.69 in the first 50-80 rings, then they became thinner, but were always well marked.

Anchovy Juveniles

- The individuals ranged between 37.3 mm and 77.8 mm (total length – TL). The growth rate of the specimens analyzed was 0.86 mm day^{-1};
- The evolution of increment width in relation to Julian date and age showed that the increment width curves were different between the three subgroups caught in November. Increment widths increased faster and had higher maximum values in the group hatched in late September whereas the two groups hatched in late August-early September were very similar and displayed a slower increase and lower maximum values for increment widths. The onset of increment width decrease was not consistent for the three groups either.
- The otolith increment widths recorded for Adriatic juvenile anchovy showed trends very similar to those observed in the Aegean Sea. Increment width increases progressively up to approximately 40-50 days (period which corresponds to metamorphosis), following metamorphosis they then start decreasing;
- All hatching date subgroups show the same "dome shaped" evolution of otolith increment widths where maximum width seems to be temperature dependent (higher maxima at higher temperatures). In autumn 2007, a rapid decrease was observed in the mean otolith increment widths during the second part of October, when the temperature started decreasing.

Aegean Sea

Anchovy Larvae

- The slopes and the intercepts of both SL-on-Age and the SL_c-on-Age relationships did not differ significantly between July 2007 and December 2007. In both cases, the growth rate was 0.8 mm day^{-1};
- The slopes of the growth-in-weight relationship did not differ significantly between seasons but anchovies in July 2007 were significantly heavier than in December 2007. The relationships of otolith radius (OR)-on-Age and OR-on-SL indicated that anchovy larvae caught in July 2007 had bigger otoliths at Age or Length;
- Anchovy larvae and their otoliths grew at the same rate in July 2007 and December 2007, however their weight and otolith size was significantly higher in July;
- Anchovy larvae captured in July 2007 had wider increments compared to those caught in December 2007.

Sardine Larvae

- Standard length ranged between 14 mm and 35 mm. The growth rate estimates were low (0.340 and 0.345 mm day^{-1}) from both relationships, SL and corrected SL and age;
- The increase in increment width was slow and the maximum values were lower than 10 μm.

Growth Aegean Anchovy Juveniles

- Juveniles captured in July were heavier at a given length and age compared to December.
- The slope of the TL-on-Age relationship was significantly higher in July than in December, indicating that the environmental conditions (e.g., temperature) were more favorable in late spring-early summer than in autumn;
- The increment widths of anchovies (caught in summer) hatched late in spring 2007 increased faster than those hatched earlier in the season. The maximum values of increment widths were higher for the former group. However, both groups exhibited similar increment widths by late July;
- For anchovies caught in December, the increment width curves were different between the three subgroups examined. They increased faster and had higher maximum values in the group hatched in late August-early September whereas the group hatched in October displayed the slowest increase and lower maximum values for increment widths;
- The relationship of increment width by age for all five subgroups revealed that maximum values for increment widths were attained at 35-55 days. After this period, which corresponds to the time required for metamorphosis, increment widths started to decrease.

Sardine Juveniles

- The slope of the length -on- age relationship was low (0.13 mm day^{-1});
- The sardine sample consisted of fish that had hatched over a three-month period (from early February to early May);
- The maximum values of increment widths were recorded for the group hatched in April;

All species/subgroups show the same "dome-shaped" evolution of otolith increment widths but the way that maximum width is reached seems to be species specific (higher in anchovy) and temperature dependent (higher maxima at higher temperatures).

Gulf of Lions

Anchovy Larvae

- The main result for the anchovy larvae in the Gulf of Lions is the extremely low growth rates presented by the December 2007 sample group (around 0.1 mm/day), while for the July sample growth rate was around 0.42 mm day^{-1};
- For both the July and December samples, increment width increased continuously, although for larvae caught in December the bigger increment width reached was half the July sample maximum increment width (4 vs. 8 microns). The differences in the environmental conditions, especially water temperature, in which larvae from the two sampling periods were hatched and developed, can be enough to explain those differences in growth rates an increment widths.

Sardine Larvae

- Sardine late larvae were sampled in January 2009 only. Standard length ranged from 13 mm to 35 mm. The growth rate estimate was 0.306 mm day^{-1};
- The increase in increment width was slow and the maximum values were lower than 5 µm.

Anchovy Juveniles
- Anchovy juvenile samples were analyzed for December 2007. The size range of the December sample (TL) was 48-95 mm and the growth rate 0.85 mm day^{-1};
- To examine the evolution of increment width in relation to Julian date and age, fish from the December sampling period were divided in three sub-groups. The increment width curves were different between the three subgroups examined. They increased faster and had higher maximum values in the September group whereas the group hatched in late October displayed the slowest increase and lower maximum values for increment widths;
- The onset of increment width decrease was not consistent for the three groups either. The group hatched earlier in the season exhibited an earlier start of increment width decrease;
- The relationship of increment width by age for all subgroups revealed that maximum values for increment widths were attained at 35-55 days. After this period, which corresponds to the time required for metamorphosis, increment widths started to decrease.

Sardine Juveniles
- The total length range of sardine juveniles collected in August 2007 was quite narrow (65-97 mm). The range of ages was also narrow (101-120 days). The length-on-age relationship gives a growth rate of 1.01 mm day^{-1};
- The relationship of increment width by age revealed that maximum values for increment widths were attained at 70-80 days, with values of around 10 µm.

5. Define and improve the selectivity of existing towed gears used to catch small pelagic fishes in the Mediterranean.

Pelagic trawls target schooling fish, which tend to group relatively homogeneously by size, thus the gear can be selective in terms of fished species (anchovy, sardine, mackerels etc.), but not necessarily so in terms of fish size. Moreover, the selectivity characteristics of pelagic trawls in the Mediterranean have never been the object of a detailed study. The need to avoid capture of undersized fish is evident and can only be achieved by substantial changes in fishing gear and techniques. In this project, the way towards an improvement of trawl net selectivity was tackled using four approaches:

(a) *Gear simulation.* With its specialized software (Dynamit) IFREMER carried out simulations of the traditional Italian trawl and the French rope trawl. The results were compared with those of the trials (see point (b) below) with the objective of optimising the designs of selective pelagic trawl gear and produce innovations in the traditional commercial pelagic trawl. The simulations allowed to propose modifications of the ratio between the warp length and the bottom depth and technical innovations for the single-boat trawl and the rigging used in Italian fisheries. These modifications were tested at sea in the Adriatic waters in June 2008 (see point (b) below). Hydrodynamic simulations were also carried out for the conception of the horizontal panel, which was mounted on the single-boat trawl used during the IFREMER sea trials (see point (c) below).

(b) *Assessment of current trawl gear selectivity.* Two fishing vessels were selected to carry out the work needed to meet this objective: (i) a trawler operating in the Adriatic pair-trawling fleet (940 HP – 1294 kW), fitted with a fixed pitch propeller (FPP) of 2.00 m diameter and a gear box of 5.42 of ratio using a semi-pelagic net, and (ii) a trawler commonly used by the Italian fleet (563 HP – 409 kW), fixed pitch propeller (FPP) of 1.80 m diameter, using a semi-pelagic single-boat trawl. Three sampling cruises were carried out: (a) November 2007: an initial evaluation of current gear selectivity of the Mediterranean pair-boat semi-pelagic trawling carried out on board vessel Nr. (i); (b) December 2007: an evaluation of the potential offered by appropriate design optimizations of single-boat pelagic trawling on board the reference vessel Nr.(ii), and (c) June 2008: direct effects of the design and rigging optimisations of single-boat pelagic trawling (obtained in point (a) above) on the pelagic communities. The

escapement through the body or through the codend was assessed by mounting small net bags on different parts of the two nets (pair- and single-boat trawl) (Figure 9).

Figure 9. Particular of the net bags mounted on the different parts of the trawl body in the sea trials carried out to evaluate current gear selectivity of single- and pair-trawlers.

The results indicated that no escapement was recorded at the codend; both in the pair- and single-boat trawls, the higher escapement ratios were found to be in the netting before the codend; higher escapement ratios were found in the single-pelagic trawling; different escapement ratios were found for different pelagic species. Gilt sardine (*Sardinella aurita*) had the highest ratios; in terms of efficiency, the single-boat pelagic trawling seems to be enforceable in the commercial Adriatic pelagic fisheries. Improvements were found to be needed and preliminary design and rigging optimisations were simulated by IFREMER using computer programs (see point (a) above). The direct effects on selectivity these optimisations were investigated in the third cruise. The results obtained indicated that escapement took place through the trawl body both of upper- and lower-netting panels of the pelagic trawl; only Anchovy were found to escape from the trawl body but this was probably due because of the strong dominance of this species in the catch; there was no a significant effect of the rigging configuration on fish escapement; the optimisation of net rigging and design seemed to positively influence the total fish escapement: the percentage of escapement increased from 2.7% to 7.6% with the traditional and modified trawl design, respectively; the total escape rate was not size dependent, the size-frequency distributions obtained from the codend catch of the pelagic trawl were not different to those of the escapees.

(c) *A study on the behaviour of fish by means of an experimental trawl using horizontal separator panels*. IFREMER performed observations at sea (Gulf of Lions) on the behaviour of fish by means of an experimental trawl using 1 horizontal separator panel and 2 superposed codends. The goal of this task was to determine if separator panels operate by segregating pelagic species entering into the French rope trawl either according to their specific behavioural reactions to the gear or to their morphological differences. Two sea trials (March and September 2008) were carried out under the same technical conditions using a commercial trawler (25 m LOA). To test the effect of the horizontal panel (Comp) on species composition of catch, a mixed-model Permutational Multivariate Analysis of Variance (PERMANOVA) was carried out and this indicated that species composition on Upper Codend (UC) was dissimilar to Lower Codend (LC) ones ($p < 0.05$).

(d) *Final cruise: collaborative experiment integrating all modifications in an innovative single-boat trawl*. A new rope trawl with a horizontal separator panel was tested in the Adriatic Sea, using the Italian Research Vessel "G. Dallaporta". Sea trials (06-16/10/09) were conducted with the trawl rigged with two different couples of superposed codends: the first with a nominal mesh size of 23 mm and the second with 15 mm. From 07/10/09 to 08/10/09, in parallel to the final cruise and in the same fishing area, an evaluation of the catch composition of the actual commercial pelagic fisheries was conducted on board the pair-boat pelagic trawler monitored in point (b) above. The results showed that: the use of different codends does not affect the trawl behaviour; Sardine and Picarel clearly preferred the upper part of the trawl, while Anchovies and Bogue have been found more abundantly in the lower-codend; a size-behaviour relationship was found for Hake and Horse Mackerel, with juveniles in the lower part and adults in the upper part of the trawl; juvenile Mackerel preferred the upper codend and adults the lower codend; the length frequency distributions show no statistically significant differences between Single- and Pair-boat trawling; and, finally, fishing depth substantially influenced the length frequency distribution of the anchovy and the sardine caught therefore and may therefore play a more important role than any other technical measure in improving the selectivity of Mediterranean pelagic trawls.

6. Improvement of current stock assessment in the Mediterranean by transfer of know-how from the Atlantic and case applications of suitable assessment methods integrating data from direct surveys and catch-at-age estimates.

One of the objectives of SARDONE was to identify and select appropriate stock assessment methodologies to effectively assess the major stocks of small pelagic fish in the Mediterranean. The applicability of the methodology successfully used to assess the stocks of Bay of Biscay anchovy and Iberian sardine in the Atlantic was studied for Mediterranean stocks in the western Mediterranean, the Adriatic and the Aegean. One of the main features of these methods is that, even if they incorporate statistical analysis of the catch at age data (as ICA software, Patterson and Melvin 1996), they are mainly based on relative population estimates from direct research surveys such as the Acoustics and the DEPM. Incorporation of direct population estimates are deemed to be a step forward to the assessment methods currently used in the Mediterranean. Furthermore, a range of alternative assessment models suitable for the characteristics of the stocks were be explored. Recent literature suggests that among others and in addition to VPA type models, different models like the biomass model attempted for southern horse mackerel and for the Bay of Biscay anchovy, length-based models or survey-based separable model like SURBA could be appropriate for the assessment of small pelagic stocks.
The overall approach to this objective consisted in:
I.   For each stock, scrutinising the available data for the assessment and reviewing its quality, putting forward several suggestions for potential improvements, as it was considered that major improvements would arise from the amelioration of the basic data set.
II.   Testing different assessment methods according to the suitability of the data available: Models such as integrated Catch at age analysis (ICA – Patterson and Melvin 1996), or Biomass difference models (Ibaibarraiga et al. 2008) or Length based analysis, (VIT, Lleonart) were checked in one or other stocks, and compared with the currently applied ones (VPA-type methods). Emphasis was also given to incorporating, when possible, the FLR (Fisheries Science in R) assessment framework (www.flr-project.org) or suitable programs in R.
III.   Selecting the best, most suitable, assessment method so far, and the alternative ones, which give complementary views to the assessment, but requiring yet some further testing or addition of more years of observations.
The work carried out during SARDONE is summarised below on an area-to-area basis:
Adriatic Sea. Since the 1990s, the assessment of both anchovy and sardine stocks in the central and northern Adriatic has been carried out by means of population dynamics methods, using time series starting in 1975. In particular, Laurec-Shepherd tuned Virtual Population Analysis (VPA) was applied using catch data collected for Italy, Slovenia and Croatia and former ex Yugoslavia. The improvements in the stock assessments gained during SARDONE are relative to input data, both

in terms of type and quality, and also to the application of new methods to estimate abundance at sea and annual fishing mortality rates F (year^{-1}); as well as in estimating natural mortality (two alternative methods were used: Probiom software (Abella et al., 1997; Caddy and Abella, 1999) and "Gislason" method (Gislason et al., 2008; Gislason et al., in press). Another improvement obtained is about the tuning data for VPA calculations: Since 2006, instead of commercial CPUE at age, an abundance at age index was obtained from the echo-surveys carried out by the acoustics unit of ISMAR-CNR and used for tuning. In the last stock assessments, in 2009, it was also possible to recover the echo-survey data, as well as biological data, relative to all the eastern side of the Adriatic, from the Institute of Oceanography and Fisheries of Split. The use of alternative population dynamics methods was evaluated for the stock assessments of both species, in addition to the Laurec-Shepherd tuned VPA. In particular, Integrated Catch Analysis (ICA), based the analysis of catch at age data, was investigated. In these analyses, the reliability of age-length keys employed to calculate the total catch at age data was explored by means of Iterated Age Length Key (IALK). ICA was essayed because catches at age are subject to errors across ages in the relative percentages of their occurrence in the sampling and to the age readings suggesting that a better use of the age structured information in both the catches and the survey indexes would be a statistical fitting of that information. Not as in VPA, where the catches at age are taken as absolute observations of fishes by age. It appears that, for anchovy, recent evolution of the stock is probably better described by the ICA assessment whilst the historical perspective is better described (or tuned) by the Laurec Shepherd tuned VPA.

Aegean Sea. a number of improvements were carried out on the data used for the assessments, both for anchovy and sardine: (i) half year, rather than annual, age-length keys (ALK) were applied to half year length distributions; (ii) historical catches were produced to give an historical perspective for the fishery; (iii) the natural mortality pattern was re-defined in order to change by age according to the Abella 1997 (Probiom algorithm). In the past M.anchovy=0.7 and M.sardine=0.8. Now for sardine M1=0.96 and M2=0.69. And for anchovy it is M1=1 and M2=0.72; (iv) problems with catchabilities of the surveys were identified and discussed. The revision of the Age reading (being carried out to date) partly solved this issue. The revision for the sardine stock was completed and incorporated in the final report of the SARDONE. The major problems of these stock assessments were the short time series of data available, as well as the fact that, in the case of short lived species (max age group 3), most VPA based assessment methods like ICA, present difficulties in resulting in a good fitting as there is a very poor convergence properties. Within the SARDONE framework the assessment of the anchovy stock in Aegean Sea was significantly improved in terms of the model fit and the reliability of the results. Moreover the development and the implementation of an R-script that allowed the application of the stock assessment using the FLR libraries (FLEDA, FLICA, FLASS), resulted in improvement in terms of the exploratory data analysis, the quick inspection of the model fit and improvement of the quality of the graphical presentation of the model results. For anchovy, besides FLICA (Integrated Catch at Age Analysis applied using R), the adopted assessment method for both species, a two stage Bayesian stock assessment model was applied for the anchovy in this region. The implementation of this alternative assessment method further improved the assessment of the anchovy stock in Aegean Sea indicating consistency with the results of the ICA. No alternative assessment methods were carried out for sardine. Based on this assessment results and the aforementioned parameters this stock is considered to be harvested sustainably, operating below but close to an optimal yield level based on the Patterson empirical reference point for the exploitation rate. The extention of the time series of data with a monitoring of the stock based upon fishery independent surveys on a regular basis is required in order to continue the assessment, estimate biomass based reference points and reduce the uncertainty on the estimation of the exploitation status of the stock.

Gulf of Lions. At the beginning of SARDONE no age composition was available, neither for the survey estimates nor for the catches. So the major suggestion for improvement was to age the collection of otoliths from the survey and the fishery monitoring in order to infer the age composition of the acoustic estimates and of the monitored catches, according to the length distribution. This has been done and recovery of the age composition has been achieved since 2002. This has allowed making some exploratory analysis with an age structure approach (like ICA), although due to its poor results in terms of residuals and high uncertainties about the actual level of natural mortality the approach was not adopted. The stocks of the main species of small

pelagics in the Gulf of the Lions are evaluated annually by acoustics since 1993. The quality of existing inputs was good (as they were performed in accordance with the international protocols as MEDIAS), but too different according the period and/or the data. This disparity limited the analytical investigation. Some DEPM surveys covering both areas together (Gulf of Lions and the Northern Cataluña sea) are used to guess what catchability factor may apply to the acoustic series available for the Gulf of Lions. As an adopted assessment, it was decided to directly fit the catches at age and age structured acoustic index, i.e. the acoustic estimates of anchovy were assumed to be unbiased indicators of the absolute level of biomass of the population, under the assumption thet catchability = 1. No analytical assessment has been carried out so far for anchovy stock in the Gulf of Lions. As there is some uncertainty about the age distribution of the stock and catches, the decision was taken to perform a length-based analysis, with the VIT software. Various sensitivity analyses on the assessment were carried out: (i) the sensitivity of the assessment to the assumptions on the Von Bertalanffy's parameters was tested. For the purposes of this exercise and simplicity, the natural mortality at age, was taken as a single fixed value, equal to 0.7, which corresponds to the value used formerly in the Adriatic for this species. This is contrary to the practice for the other cases studies were M vectors at age were obtained using ProdBiom2009 excel file (Abella et al., 1997; 1998), taking into account the parameters of the Von Bertalanffy's growth curve; (ii) the sensitivity of the assessment to the mortality vector at age considered was performed. For this exercise, Von Berlatanffy's parameters has been fixed to the values reported in GCFM 2009 (Linf=19.1, K=0.35 and t0=-1.45), such as the length-weight relationship (a=0.0038 and b=3.197). For both species, the assessment results are highly dependent on growth parameters, and hence on the range of age classes sustaining the catches. This immediately leads to stress the relevance of an accurate growth studies and age determination for this fishery in order to obtain some meaningful assessment of the exploitation pattern exerted by the fishery. For an improvement, it is suggested to pursue the effort to standardize all data sets (year by year), as key size/age, sexual maturation, fecundity and spawning success, survival and mortalities and catch per unit effort for operational units. Despite the likely connections between the fisheries in the Gulf of Lions and the Northern Cataluña for the small pelagics, no common data base has been set up for the assessment. Therefore, with the aim of assessing shared stocks, re-enforcement of the cooperation between France and Spain to actualise biological data as well as catch and effort data collection for the boats of the two countries catching anchovy and/or sardine in the Gulf of Lions is desirable.

The premises for the proposal of SARDONE were the fact that some stocks of small pelagic species in the Mediterranean were over-exploited, but the management measures which may have remedied the situation were not well understood. A need had emerged to better understand the distribution of post-larval stages and how this distribution depends on oceanographic features. Furthermore, post-larval sardines and anchovies are caught in locally important mixed small-scale artisanal fisheries but little is known about the effect this mortality has on the yield of larger sardines and anchovies. A clear need thus emerged for a sound scientific basis upon which the improvement of the management of sardine and anchovy exploitation in the Mediterranean could be based. SARDONE fulfilled these requirements exactly. In fact, one part of the research was developed juvenile surveys towards the proper management of the resource, whilst another part focused on the characterization of nursery areas, through retrospective analysis of past acoustic surveys, and field investigations. The problems related to understanding of post-larval and juvenile ecology and the impacts of fry fisheries were tackled and the information gained will aid the development of monitoring tools, has filled gaps in present knowledge, and has allowed the development, lest still preliminary, of a tool to assess the impact of these fisheries on the adult stocks. In particular the specific question of linking occurrence of concentration of late larvae to oceanographic processes in the region was approached through the use of hydrodynamic and Lagrangian modelling and has yielded important results which are crucial for the future development of forecasting tools aimed at improving the fishery management of these resources. Finally, the current stock assessment practice in the Mediterranean has been reviewed, the feasibility of applying models, allowing for an adaptive management, currently used in the Atlantic, was explored, and finally ameliorative methods were applied ensuring the best assessment outputs possible with the data and methods available at present. Of course the final impact of these results

will depend on the degree of implementation of the improved scientific advice by the institutions in charge of the management of fisheries resources in the Mediterranean, i.e. the General Fisheries Commission for the Mediterranean (GFCM) and the Fisheries Directorate of the various Mediterranean countries. The project results have communicated to the Scientific Advisory Committee of the GFCM through a communications at the annual Sub Committee for Stock Assessment (SCSA) which was held in Malaga at the end of 2009 (1 – 4 December 2009), and shortly will be available for consultation on the SARDONE website at
http://www.ismaran.it/ismaran/projects/sardone/sardone.html

2. Dissemination and use

Plan for using and disseminating the knowledge

Section 1 - Exploitable knowledge and its Use

Overview table of exploitable results

Exploitable Knowledge	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable for commercial use	Patents or other IPR protection	Owner & Other Partner(s) involved
1. Innovative single-boat trawl for small pelagic species in the Mediterranean	Fishing gear	1. Fishing industry	2010 - 2013	N/A	**ISMAR – CNR & IFREMER**

1.   Innovative single-boat trawl for small pelagic species in the Mediterranean

- *What the exploitable result is (functionality, purpose, innovation etc.)*
The exploitable result is an innovative single-boat pelagic trawl (fishing gear) to catch small pelagic species in the Mediterranean. It is a "species selective" gear which could make use of fish behaviour to separate the different species during the catching process so that each is subject to a selection process more appropriate to its size and morphology.

- *Partner(s) involved in the exploitation, role and activities*
CNR-ISMAR (partner 1) and IFREMER (partner 4) were involved in the development of this fishing gear having conducted collaborative experiments to document the direct effects of such an innovative pelagic towed gear on the pelagic biological communities.

- *How the result might be exploited (products, processes) - directly (spin offs etc) or indirectly (licensing)– on an individual basis or as a consortium/group of partners*
This innovative fishing gear, experimented during SARDONE, is a highly selective single-boat pelagic trawl, which could represent an easy-to-use and useful solution for the Italian fishing fleet targeting small pelagic species. To date the Italian pelagic trawl fishery is mainly composed of pair trawlers. At the moment Italian fishermen are willing to experiment the new single-boat trawl for different reasons. Firstly, to avoid the current problems related to the use of two boats (safety, autonomy, etc...); secondly to improve the fishing efficiency (energy use, catch efficiency etc...) and selectivity.
The results can be directly exploited by commercial vessels, by simply transferring the knowhow and expertise achieved during the SARDONE project.

- *Further additional research and development work, including need for further collaboration and who they may be*
In order to enhance catch efficiency, the new trawl should be tested in combination with specific instrumentation for the detection of pelagic schools. Commercially, the pair trawlers, make use of two echo-sounders (one per boat) allowing a wider area to be explored compared to that explored by one single boat. In this way, pair trawling is more efficient in the fish detection. For this reason the single-boat pelagic trawl should be supplied with a sonar which will allow the single boat to explore a wider volume of water. This could improve the catch efficiency, which is the main concern for fishermen.

- *Intellectual Property Rights protection measures (patents, design rights, database rights, plant varieties, etc – include references and details)*
N/A

- *Any commercial contacts already taken, demonstrations given to potential licensees and/or investors and any comments received (market requirements, potential etc.)*

During the final collaborative cruise both the Italian and French fishermen were invited onboard the research vessel "G. Dallaporta", and participated to the curuise. Their participation was beneficial in two directions: (i) towards the development of the gear: their experience was extremely useful for the improvement of the experimental trawl; and (ii) as a means of divulgating the usefulness of the gear: being on board allowed them to verify the potential of the new trawl net and how it could be used commercially.

- *Where possible, also include any other potential impact from the exploitation of the result (socio-economic impact).*

No predictions can be made at this time on other potential impacts that could arise from the exploitation of this innovative fishing gear.

Section 2 – Dissemination of knowledge

Dissemination of knowledge: Overview table

Planned/actual Dates	Type	Notes	Type of audience	Countries addressed	Size of audience	Partner responsible /involved
Established within 12 months of the start	Project web-site http://www.ismaran.it/ ismaran/projects/sard one/sardone.html.		Everybody			All
Established within 6 months of the start	Project leaflet	A second leaflet is in the process of being produced	Everybody	Distributed at GFCM meetings and at other conferences		All
April 2007	Conference	38th CIESM Congress, Istanbul	Scientific, Managers, Stakeholders	Mediterranean	100+	HCMR
July – August 2007	Lecture	Training course for managers and senior staff of fisheries and aquaculture of Venezuela "Realizacion de una planta fileteadora de pescado en la isla Margarita – Edo. Nueva Esparta"	Managers, Stakeholders	Venezuela	20+	ISMAR
September 2007	Conference	13th Panhellenic ichthyological symposium	Scientific	Greece	40+	HCMR
10-14 September 2007	Conference	Presentation of SARDONE at the Scientific Advisory Committee (SAC – GFCM), Sub-Committee on Stock Assessment (SCSA) in Athens	Scientific, Managers, Stakeholders	Mediterranean	50+	All
23-25 June 2008	Conference	Jonsmod (Joint numerical Modelling Sea Group) Meeting	Scientific	European	30+	IFREMER
2008	Conference	5th World Fisheries Congress	Scientific, Managers, Stakeholders	Worldwide	200+	HCMR

Planned/actual Dates	Type	Notes	Type of audience	Countries addressed	Size of audience	Partner responsible /involved
18-22 May 2009	Conference	ICES Working Group on Fisheries Science and Technology Annual Meeting	Scientific, Managers, Stakeholders	Mediterranean, Northern European	60+	HCMR, ISMAR, UNIVPM
22-25 September 2009	Conference	XIX Congresso dell'Associazione Italiana di Oceanologia e Limnologia	Scientific	European	30+	ISMAR, UNIVPM, OGS, CSIC
1-4 December 2009	Conference	Presentation of SARDONE results at the Scientific Advisory Committee (SAC – GFCM), Sub-Committee on Stock Assessment (SCSA) in Malaga	Scientific, Managers, Stakeholders	Mediterranean	50+	All
2009	Conference	4 contributions at the 9th Panhellenic Symposium of Oceanography and Fisheries	Scientific	Greece	40+	HCMR
2 July 2009	Seminar	Keynote speech on fishing technologies	Managers, Stakeholders	Italy	40+	ISMAR
March 2010	Conference	Workshop on Egg Production Methods for estimating fish biomass	Scientific	European	30+	CSIC
6-9 May 2010	Conference	14th Panhellenic ichthyological symposium	Scientific	Greece	40+	HCMR
10 - 14 May 2010	Conference	6 contributions at the 39th CIESM Congress	Scientific	European	100+	All
13-14 September 2007	Working document	4 documents produced at the Sub-Committee on Stock Assessment of GFCM	Scientific, Managers, Stakeholders	Mediterranean	40+	HCMR
25-30 October 2009	Working document	2 documents produced at the Sub-Committee on Stock Assessment of GFCM	Scientific, Managers, Stakeholders	Mediterranean	40+	HCMR, ISMAR
8-12 June 2009	Working document	2 documents produced at the SGMED-09-02	Scientific, Managers, Stakeholders	Mediterranean	40+	HCMR
2008	Scientific publication	Hydrobiologia	Scientific	Worldwide		HCMR

Planned/actual Dates	Type	Notes	Type of audience	Countries addressed	Size of audience	Partner responsible /involved
2009	Scientific publication	Ocean Dynamics	Scientific	Worldwide		IFREMER
2009	Scientific publication	Marine Ecology Progress Series	Scientific	Worldwide		OGS, ISMAR
In press	Scientific publication	Advances in Oceanography and Limnology	Scientific	Worldwide		ISMAR, UNIVPM
Submitted	Scientific publication	Advances in Oceanography and Limnology	Scientific	Worldwide		ISMAR, HCMR
Submitted	Scientific publication	Fisheries Oceanography	Scientific	Worldwide		HCMR. ISMAR, IFREMER
2009	Fishing journal	Gazzettino della Pesca	Managers, Stakeholders	Italy	Monthly magazine of the Italian fishing sector	ISMAR
2009	Newspaper article	Il Sole 24 Ore	General public	Italy	Daily national economics newspaper	ISMAR
17 March 2010	Newspaper article	Il Piccolo	General public	Italy	City of Trieste	OGS

Dissemination of knowledge: Detailed list of dissemination material

Peer-reviewed journals

WP 1
HCMR
Tsagarakis K., A. Machias, S. Somarakis, M. Giannoulaki, A. Palialexis, C. Papaconstantinou, & V. Valavanis, 2008. Habitat discrimination of juvenile sardines in the Aegean Sea using remote sensing environmental data, Hydrobiologia 612: 215-223

ISMAR, HCMR

Leonori I., De Felice A., Gramolini R., Campanella F., Giannoulaki M., Machias A. and Valavanis V.D. 2010. Use of GAMs analysis for the identification of anchovy juvenile habitat in the Adriatic Sea, Submitted in Advances in Oceanography and Limnology

HCMR. ISMAR, IFREMER

Giannoulaki M, Pyrounaki M. M., Liorzou B., Leonori I., Valavanis D. V., Tsagarakis K., Bigot J. L., Roos D., De Felice A., Campanella F., Somarakis S., Arneri E., Machias A. 2010. Habitat suitability modelling for sardine juveniles in the Mediterranean Sea. Submitted in Fisheries Oceanography

WP2
IFREMER
Nicolle A., Garreau P., Liorzou B. (2009) Modelling for anchovy recruitment studies in the Gulf of Lions (Western Mediterranean Sea). Ocean Dynamics 59,6 ; 953-968
DOI10.1007/s10236-009-0221-6

ISMAR
R Gramolini, A Russo, A. Coluccelli, M. La Mesa, M. Panfili, E.B. Morello, E Arneri. Numerical simulations of transport of small pelagics eggs and larvae in the Adriatic Sea. (in preparation for Advances in Oceanography and Limnology)

WP3
OGS, ISMAR
Borme D , Tirelli V , Brandt SB, Fonda Umani S & E Arneri (2009) Diet of *Engraulis encrasicolus* (L.) in the northern Adriatic Sea (Mediterranean): ontogenetic changes and feeding selectivity. Marine Ecology Progress Series, 392:193-209.

Conferences/Presentations

WP0

Arneri, E. SARDONE, Improving assessment and management of small pelagic species in the Mediterranean. Scientific Advisory Committee (SAC – GFCM), Sub-Committee on Stock Assessment (SCSA) in Athens on 10-14 September 2007.

Morello, E. & Arneri, E. SARDONE, Improving assessment and management of small pelagic species in the Mediterranean: results. Scientific Advisory Committee (SAC – GFCM), Sub-Committee on Stock Assessment (SCSA) in Malaga on 1-4 December 2009.

WP1

HCMR

Tsagarakis K., Somarakis S., Machias A., Giannoulaki M., Valavanis V., Palialexis A. & C. Papaconstantinou, 2007. Preliminary analysis of the habitat characteristics of anchovy and sardine in the Aegean Sea in relation to fish size. Proceedings of the 38th CIESM Congress, Istanbul, April 2007, p.621.

Papaconstantinou C., Tsagarakis K., Machias A., Somarakis S., Giannoulaki M., Valavanis V. & A. Palialexi, 2008. Habitat discrimination of juvenile European Anchovy in the Aegean Sea (Greece). 5th World Fisheries Congress, Book of abstracts, 331

Giannoulaki M., Liorzou B., De Felice A., Leonori I., Valavanis V., Machias A., Pyrounaki M. M., Tsagarakis K., Roos D., Gramolini R. & E. Arnerni, 2009. The use of acoustics in identifying small pelagics' juvenile habitat in the Mediterranean. ICES Working Group on Fisheries Science and Technology Annual Meeting, Ancona 18-22 May 2009

Tsagarakis K., S. Somarakis, M. Giannoulaki, A. Machias, V. Valavanis, A. Palialexis, & C. Papaconstantinou, 2007. Habitat discrimination of juvenile anchovy and sardine in the Aegean Sea, Proceedings of the 13th Panhellenic ichthyological symposium, Mytilini, September, p 69-72 (in greek with english abstract)

Giannoulaki M., Valavanis V., Palialexis A., Tsagarakis K., Machias A. & S. Somarakis, 2009. Changes in potential habitat of anchovy (Engraulis encrasicolus) in the N. Aegean during early summer based on satellite environmental data. Proceedings of the 9th Panhellenic Symposium of Oceanography and Fisheries, Volume II, pp. 834-839 (in greek with english abstract)

Pyrounaki M. M., Giannoulaki M., Tsagarakis K. & A. Machias, 2009. Spatial modeling of the presence of juvenile sardine (Sardina pilchardus W.) schools in relation to satellite environmental data in the northern Aegean Sea. Proceedings of the 9th Panhellenic Symposium of Oceanography and Fisheries, Volume II, pp. 901-905 (in greek with english abstract)

WP 2

IFREMER
Long term modelling for anchovy recruitment studies in the Gulf of Lion and the Catalan Sea.
Amandine Nicolle and Pierre Garreau (Ifremer)
Jonsmod (Joint numerical Modelling Sea Group) Meeting
Bergen 23-25th June 2008

ISMAR
Simulazioni numeriche delle traiettorie di uova e larve di piccoli pelagici in Adriatico
XIX Congresso dell'Associazione Italiana di Oceanologia e Limnologia
Venezia, Isola di S. Servolo - 22-25 settembre 2009

Numerical simulation of small pelagic fishes eggs and larvae in the Adriatic Sea.
R. Gramolini, A. Russo, A. Coluccelli , M. La mesa , M. Panfili , E. B. Morello and E. Arneri (UPM/ISMAR)
39th CIESM Congress – Venice, Italy, 10 - 14 May 2010

CSIC
Andrés Ospina-Álvarez and Isabel Palomera (ICM-CSIC.) Setting up an egg-density model for European anchovy. *39th CIESM Congress – Venice, Italy, 10 - 14 May 2010*

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Schismenou E., Lefkaditou E., Giannoulaki M., Machias A. & S. Somarakis, 2009. Otolith microstructure and growth of juvenile anchovy (Engraulis encrasicolus) in the N. Aegean Sea. Proceedings of the 9th Panhellenic Symposium of Oceanography and Fisheries, Volume II, pp. 868-871 (in greek with english abstract)

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Tirelli V, Borme D, Legovini S, de Olazabal A, Grilli F & I Palomera (2009) What is there to eat for small pelagic fish along the western Adriatic coast? Zooplankton assemblages collected by two different nets off the Po river delta and in the Gulf of Manfredonia (Italy). *XIX Congresso dell'Associazione Italiana di Oceanologia e Limnologia, Venezia, Isola di S. Servolo - 22-25 settembre 2009*

ISMAR
Panfili, M., Donato, F., Morello, E.B. & Arneri E. 2009. Growth rates of early life stages in *Engraulis encrasicolus* and S*ardina pilchardus* in the Adriatic sea (Italy). *39th CIESM Congress – Venice, Italy, 10 - 14 May 2010*

WP4
ISMAR
Invited keynote speaker at the Seminary "Technological innovations, energy saving and environmental sustainability in professional fisheries, implementations and applications" 02/07/2009, Mazara Del Vallo (Sicily, TP). Invited by the Italian National Association of the Fishing Cooperatives "Lega Pesca".

Lecturer in a multi-disciplinary training course for managers and senior staff of fisheries and aquaculture of Venezuela "Realizacion de una planta fileteadora de pescado en la isla Margarita – Edo. Nueva Esparta" organised by Frigo Tecnica Internazionale spa (MC) held at the "Campus Margarita della Fundacion La Salle de Ciencias Naturales" (Venezuela) from 06/07/2007 to 10/08/2007 in collaboration with the Fondo de Crédito Industrial of the Venezuelan Government, the Province of Ascoli Piceno, the Polytechnic University of Marche Region and the Fishing Associations of the Marche Region. During the training course the main findings of the SARDONE work with the single-boat trawl have been presented to managers and senior staff of fisheries and aquaculture of Venezuela.

WP 5
HCMR
Antonakakis I. K., Giannoulaki M., Kallianiotis A., Somarakis S. & A. Machias (submitted). European sardine (*Sardina pilchardus*) stock assessment in Northern Aegean Sea. Proceedings of the 14th Panhellenic ichthyological symposium, Piraeus, May 6-9 (in greek with english abstract).

Working documents

WP1
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Giannoulaki M., Schismenou E., Somarakis S., Machias A., Tsagarakis K., Siapatis A., Kallianiotis A. & C. Papaconstantinou, 2007. Geostatistical analysis of co-occurring anchovy and sardine populations from acoustic and ichthyoplankton data in Aegean Sea and the effect of coastal topography on their spatial characteristics. Working Group on small pelagic species. Sub-Committee on Stock Assessment. GFCM. Athens, 13-14 September, Working document, 20 pp.

Machias A., Giannoulaki M., Somarakis S., Schismenou E., Tsagarakis K., Siapatis A., Stamataki C., Vassilopoulou V., Kallianiotis A. & C. Papaconstantinou, 2007. Acoustic biomass estimates of sardine in the Aegean Sea (June 2003, 2004, 2005 and 2006). Working Group on small pelagic species. Sub-Committee on Stock Assessment. GFCM. Athens, 13-14 September, Working document, 12 pp.

Somarakis S., Machias A., Giannoulaki M., Schismenou E., Tsagarakis K., Siapatis A., Stamataki C., Torre M., Anastasopoulou K., Vassilopoulou V., Kallianiotis A. & C. Papaconstantinou, 2007. Ichthyoplanktonic and acoustic biomass estimates of anchovy in the Aegean Sea (June 2003, 2004, 2005 and 2006). Working Group on small pelagic species. Sub-Committee on Stock Assessment. GFCM. Athens, 13-14 September, Working document, 29 pp.

WP5
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Giannoulaki M., Somarakis S., Machias A., Kallianiotis A. Tserpes G., Petrakis G. & C. Papaconstantinou, 2007. Preliminary results from stock assessment of the Aegean Sea anchovy stock by Integrated Catch at age analysis. Working Group on small pelagic species. Sub-Committee on Stock Assessment. GFCM. Athens, 13-14 September, Working document, 15 pp.

Giannoulaki M., Somarakis S., Machias A., Kalianiotis A., Papaconstantinou C. 2009. Stock assessment of anchovy and sardine in GSA 22 (2000-2006) with Integrated Catch at Age analysis. Working Group on small pelagic species. Sub-Committee on Stock Assessment. GFCM., Ancona , 25-30 October 2009.

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Giannoulaki M. 2009. Stock assessment of anchovy *Engraulis encrasicolus* in GSA 22. COMMISSION STAFF WORKING DOCUMENT, THE SCENTIFIC, TECHNICAL AND ECONOMIC COMMITTEE FOR FISHERIES, Report of the SGMED-09-02: Mediterranean IV - Assessments of demersal and small pelagic stocks, Sardinia (Italy), 8-12 June 2009

ISMAR
Santojanni, A., Carpi, P., Cingolani, N., Arneri, E. 2009. Stock assessment of anchovy and sardine in GSA 22 (2000-2006) with Integrated Catch at Age analysis. Working Group on small pelagic species. Sub-Committee on Stock Assessment. GFCM., Ancona , 25-30 October 2009.

National newspapers/magazines

Sala A, 2009. Solutions and technological innovations for improving the energy efficiency. Il Gazzettino della Pesca, 03: 8 (The Fishery News Sheet, article in Italian). [ISSN 1721-6672].

Lucchetti A, Sala A, 2009. In the fishing sector, technological innovations, research and experimentations. Centro Nord – Il Sole 24 Ore, Nr. 18: 16. [ISBN 88-8363].

Il Piccolo. 17 marzo 2010. L'OGS studia il plankton per capire come cambiera' la pesca dei sardonic. Progetto europeo per migliorare la comprensione e la gestione dei pesci pelagici nel Mediterraneo. P 30.

Section 3 - Publishable results

1.   Innovative single-boat trawl for small pelagic species in the Mediterranean

- *Result description (product(s) envisaged, functional description, main advantages, innovations)*

The main objective of the project was to reduce the "through-the-mesh mortality" of small pelagic species in pelagic trawls, which can be very high. The problem was tackled initially through an assessment of the selectivity of current pelagic trawls, and then by evaluating the potential selective optimisations of both trawl design and rigging. During the project a new single-boat pelagic trawl net and a new rigging were developed. The new rope trawl and configuration were demonstrated to be more selective than the traditional pelagic net. Moreover, in addition to these solutions, a horizontal separator panel was tested in order to determine if separator panels operated by segregating pelagic species entering into the net according to their specific behavioural reactions to the gear. The separator panel was efficient only for certain species.

One of the main of the advantages of the innovation is the single-boat operability of this trawl, reducing safety problems and enhancing energy saving.

- *Possible market applications (sectors, type of use ..) or how they might be used in further research (including expected timings)*

The innovation can be easily applied to any fishing fleet targeting small pelagic species. In fact, even if the experiments were carried out onboard a research vessel, which is not as efficient as a commercial one, in most cases catches were high and comparable to those obtained by the pair trawlers.

- *Stage of development (laboratory prototype, demonstrator, industrial product...)*

Gear simulation was carried out using specialized software (DynamiT) by which the traditional Italian trawl and the French rope trawl were simulated. The results have been used with the objective of optimising both the design and rigging of pelagic trawl gears and producing innovations in the traditional commercial pelagic trawl. These modifications were tested at sea in the Adriatic waters. Hydrodynamic simulations were also carried out for the conception of the horizontal panel.

- Contact details

Antonello Sala, ISMAR – CNR, Largo Fiera della Pesca 1, 60125 Ancona, Italy
Email: a.sala@ismar.cnr.it
Phone: +390712078824
Fax: +3907155313