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Research program carried in cooperation with NATO Undersea Research Center, La Spezia, Italy

14. ABSTRACT

Ship-based surveys were carried out to provide baseline information about marine mammal presence, distribution and acoustic behaviour in the Ligurian Sea (Cetacean Sanctuary). Combined acoustic and visual surveys were mainly carried out during the SIRENA cruises organized by NURC within the SOLMAR Project. Acoustic monitoring with towed arrays was performed 24h/day to investigate the diel acoustic patterns and to provide support to the WHOI sperm whale tagging project. A lightweight wideband towed array and a complete asset for wideband signal recording and analysis were developed and tested. The system was improved with GIS plotting capabilities to provide real-time maps of acoustic contacts. Databases (strandings, sightings, acoustic contacts, literature) developed within SOLMAR have been updated.

15. SUBJECT TERMS

Underwater bioacoustics, marine mammals, acoustic signatures, Mediterranean Sea

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FINAL REPORT

GRANT #: N00014-03-1-0901

PRINCIPAL INVESTIGATOR: Dr Gianni Pavan

INSTITUTION: Centro Interdisciplinare di Bioacustica e Ricerche Ambientali dell'Università di Pavia, Italia

GRANT TITLE: Bioacoustic characterization of the Mediterranean Sea

AWARD PERIOD: 1 June 2003 - 30 September 2004

OBJECTIVE:

The goals of the project are the classification of species-specific sounds of cetaceans occurring in the Mediterranean Sea and adjacent waters; the understanding of marine mammals' behavior, the study of their ecological role and of their habitat use according to local oceanography, the study of their critical habitats and of their sensitivity to human activities, the evaluation and monitoring of noise sources possibly affecting cetacean hearing and behavior, the development of acoustic methods for the detection, monitoring and census of animals.
The ultimate goal is to provide scientific data and methodologies for supporting conservation strategies and for the definition and application of Acoustic Risk Mitigation Policies.
The project is within the frame of the NURC SOLMAR Project (NATO Underwater Research Center, La Spezia, Italy; formerly SACLANT URC) and was developed in strict coordination with NURC.

APPROACH:

The project was equally based on field research and on the development and testing of equipment to collect information on acoustic and observable behaviors of cetaceans. Bio-oceanographic parameters were also collected whenever possible to characterize the environment and to investigate on those parameters possibly affecting cetacean presence.

By participating to Sirena research cruises within the SOLMAR Project and to other sea trials it was possible to survey wide areas to provide baseline information about presence, distribution and acoustic activity of animals.
Acoustic monitoring was performed mainly with towed arrays 24h/24h to provide information on ambient noise and cetaceans acoustic activity all day round; radio-linked sonobuoys were also used to monitor specific areas or when arrays were not available.

Also, by participating to sea trials (sonar tests and seismic surveys) requiring the implementation of mitigation policies, it was possible to learn about the real conditions in which such policies have to be effective and to further improve equipment and protocols to optimize detection capabilities and data sharing among different research groups and teams on the ship.

These activities are aimed at 1) creating or updating databases on marine mammals' habitats and behaviours, 2) improving and testing passive acoustic methods in real conditions and 3) comparing them with traditional sighting methods to possibly develop operative and data processing synergies for mitigation purpose.

ACCOMPLISHEMENTS:

Support to the implementation of the NURC Marine Mammals Acoustic Risk Mitigation Policy on the NRV Alliance (17-18 September 2003, 27-31 January 2004) during sonar trials and to the implementation of the NMFS Policy in seismic survey in the South East Caribbean Sea (April 17th - June 3rd 2004) on the RV Maurice Ewing (Columbia University / LDEO).

Participation to the NURC SOLMAR Project by providing scientific support, equipment, personnel and training. Based on policies' requirements and SOLMAR needs, the equipment (sensors and analysis workstation) developed at CIBRA were improved and extensively tested.

Within SOLMAR, CIBRA participated to SIRENA 03 cruises by providing equipment, scientists and scientific support for planning and conducting the following trials:
NRV Alliance (23 August - 11 September 2003)
CRV Leonardo (3 to 11 September 2003)

Tasks included:
-Acoustic monitoring with towed arrays
-Deep hydrophone monitoring in nocturnal stations
-Support to acoustic search and tracking of sperm whales for the WHOI tagging project
-Acoustic monitoring during active trials on tagged whales

Sirena 04 was cancelled, but CIBRA participated to the Vulcano 04 (April 27 to May 15, 2004) NURC sea trial by providing equipment and personnel to perform wideband acoustic recordings and acoustic propagation tests

Analysis of recordings (0-90 kHz) made by EARS buoy deployed in the Ligurian Sea for 18 days (September 2003)

CIBRA supported the development of the SOLMAR Databases, in particular those related with cetacean strandings on the Italian coasts.
In cooperation with the Italian Stranding Network, managed by Centro Studi Cetacei, the Natural History Museum of Milan and SPAWAR (Angela D'Amico, San Diego, US) the database of the Cuvier's beaked whales strandings occurred in the Mediterranean Sea has been completed. The work was based on the collection of original stranding records, published stranding reports, newspapers' articles, data on skeletons in Museums, and any published article containing information about stranded animals.

SIGNIFICANCE:

The project supports the US Navy's and ONR's research programs on the effects of underwater noise on marine mammals and on the marine environment in general; it is aimed at developing instruments, procedures and skills for detecting cetaceans present in an area, for research and for the implementation of risk mitigation policies such as

the NURC Marine Mammals Risk Mitigation Policy, to be applied during sonar trials, and the NMFS Policy to be applied in seismic surveys.

The acoustic equipment developed within the project proved to be a very effective monitoring tool for the implementation of mitigation policies aimed at reducing the impact on marine mammals of underwater high power acoustic sources, either sonars or airguns. The combination of visual observationa with the use of suitable sensors and sound analysis/display systems maximizes the ability to reveal the presence of vocalizing animals in the operation area and thus to warn about a possible threat to marine life.

The research significantly contributed to the Mediterranean Sea databases (strandings, sightings, marine mammals acoustic signatures) being developed at NURC.

Acoustic signatures of marine mammals collected within the project have been included in the Cetacean Digital Sound Library maintained at CIBRA. This library provides sound samples to other researchers and institutions. The classification scheme for biological sounds developed by CIBRA is used in the NURC SOLMAR project and has been adopted as a basis for developing automatic acoustic classification software.

PATENT INFORMATION: none

AWARD INFORMATION: none

PUBLICATIONS AND ABSTRACTS:

Peer-Reviewed Journal Articles

FOSSATI C., MANGHI M., PAVAN G., PRIANO M., 2003. Stima acustica della crescita di un capodoglio (*Physeter macrocephalus* Linneaus, 1758) ricatturato in Mar Ligure. Atti Soc. it. Sci. nat. Museo civ. Stor. nat. Milano, 144 (I): 75-81.

RICCOBENE G., COSENTINO L., MUSUMECI M., PAVAN G., SPEZIALE F., 2004. Acoustic detection of UHE neutrinos: a station for measurement of the deep sea acoustic noise. Nuclear Instruments and Methods in Physics Research A 518 (2004): 220-222.

PAVAN G., FOSSATI C., MANGHI M., PRIANO M., 2004. Passive acoustics tools for the implementation of Acoustic Risk Mitigation Policies. In "Proceedings of the workshop on Active sonar and cetaceans", 17th ECS Conference, March 2003, P. G. H. Evans and L. A. Miller Eds., EUROPEAN CETACEAN SOCIETY NEWSLETTER NO. 42 - SPECIAL ISSUE: 52-58.

Technical Reports (Non-Refereed Publications)

G.RICCOBENE, L.COSENTINO, G.PAVAN, S.PRIVITERA, F.SPEZIALE.
A deep sea station for measurement of acoustic noise at the NEMO test-site. INFN-LNS Report 2003.

In press

Pavan G., Podesta M., D'Amico A., Portunato N., Fossati C., Manghi M., Priano M., Quero M., Teloni V. - A GIS and associated database for the Italian Stranding Network. A cooperative project based on GIS technologies. European Research on Cetaceans, 16.

Manghi M., Pavan G., Fossati C., Priano M. - Mapping and analyzing acoustic surveys' results: a GIS approach. European Research on Cetaceans, 16.

Fossati C., Manghi M., Pavan G., Priano M. - Dual use technology on cetacean research in the Mediterranean Sea: wide area aerial surveys with audio recordings from air-launched sonobuoys. European Research on Cetaceans, 17.

Manghi M., Fossati C., Pavan G., Priano M. - Diel occurrence of characteristic acoustic emission in feeding striped dolphins. European Research on Cetaceans, 17.

R. Gobbo, M. Manghi, R. Trucchi - Aerial and surface cetacean survey. An efficiency comparison during a seasonal whale-watching activity in the Mediterranean Sea.

PODESTA' M., D'AMICO A., PAVAN G., DROUGA A., KOMNENOU A., PORTUNATO N.; A Review of *Ziphius* cavirostris Strandings in the Mediterranean Sea. Submitted

Bioacoustic Characterization of the Mediterranean Sea
SOLMAR

A research program granted by the
ONR Marine Mammals Biology Program

ONR Grant N00014-03-1-0901
Granted period: June 25, 2003 – September 24, 2004

TECHNICAL REPORT

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TECHNICAL REPORT

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Award Period:	June 25, 2003 – September 24, 2004
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Bioacoustic Characterization of the Mediterranean Sea / SOLMAR

Scientific and Technical Objectives

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These activities are aimed at 1) creating or updating databases on marine mammals' habitats and behaviours, 2) improving and testing passive acoustic methods in real conditions and 3) comparing them with traditional sighting methods to possibly develop operative and data processing synergies for mitigation purpose.

Accomplishments

Scientific support to the implementation of Mitigation Policies

During the period June 2003 – June 2004, CIBRA tested different instruments, software and techniques in the implementation of the Marine Mammals Acoustic Risk Mitigation following two different protocols for NURC (NATO) and NMFS (USA).

Participation to NURC sea trials to implement the NATO marine mammals mitigation policy

Cruise onboard the NATO RV Alliance (17-18 September 2003) to implement the NURC Marine Mammals Risk Mitigation Policy during sonar trials.

Cruise onboard the NATO RV Alliance (27-31 January 2004) to implement the NURC Marine Mammals Risk Mitigation Policy during sonar trials.

During these cruises both stationary and towed arrays were used, according to the ship's activity. Both visual and acoustic methods were applied to ensure the experiment area was clear.
Data about animals' historical occurrence in the area, seasonal trophic condition and basic oceanographic features were collected before the cruise (bibliographic data).
This allowed to tune up scientists attention on the environmental conditions of the area and largely anticipated what observed during the sea trials. Limits and possible solutions or improvements were listed and analyzed for future reference (NURC internal reports).

Participation to seismic surveys to implement the mitigation policy required by NMFS

The seismic survey took place on April 17th – June 3rd 2004, in the South East Caribbean Sea, on RV Maurice Ewing (NSF, USA). The survey was organized by Rice University (Huston, Texas) and Columbia University / LDEO (Lamont-Doherty Earth Observatory). The mitigation protocols were issued by NMFS. During the experiment, CIBRA scientist on board was in charge of the acoustic side, but involved in visual observation as well. New software and instruments, partly developed according to previous experience in the implementation of Marine Mammals Mitigation (NURC) were tested, in order to set up a more user-friendly and comprehensive set of tools for collecting and showing in real time to the operators all the relevant information useful to achieve the best "situation awareness" before and during airgun operation.
24 hours/day acoustic monitoring was made with a commercial towed hydrophone, visual observation (daylight) were based on high quality binoculars and one Big Eye.
Despite of constant bad sighting conditions, almost all the species common in the area were sighted and acoustically detected. According to the applied NMFS permit, power down and shut down of the power sources occurred all times cetaceans or sea turtles were seen inside the safety radius by the visual team (Smultea et al., 2004).

As already reported in bibliography, acoustic contacts were far more frequent than the visual ones. Though, acoustic localization, range estimation in particular, resulted difficult with the available tools. Acoustics anyway demonstrated to be a necessary tool to rise and drive the observers' attention. Improvements to the current acoustic hardware and software are highly desirable to achieve a larger bandwidth and a reliable localization and range estimation of biological sound sources.

SIRENA 03

NRV Alliance Phase I – 23/08 - 02/09
Acoustic recording, monitoring and classification with towed arrays
Deep hydrophone monitoring in nocturnal stations
Fish monitoring during nocturnal stations using Simrad fishfinder

NRV Alliance Phase II – 03/09 – 11/09
Support to acoustic search and tracking of sperm whales for the WHOI tagging project
Complimentary acoustic monitoring
Acoustic monitoring while performing active trials on tagged whales

"Deep nacchere" experiment
To acoustically determine the vertical movement of feeding striped dolphins, nearby the ship, on selected night stations, a protocol was designed and followed.
A wideband vertical two-element hydrophone array, with one deep hydrophone at -250m and one at -50m, was used to record time delays on direct clicks and surface reflected clicks during peculiar click sequences named "nacchere".

To check if a "prey field" was recursively forming at relatively shallow depth, and to check if this prey field depth was consistent with the depth of the feeding dolphins, a 120kHz SIMRAD fish finder was used.
Three stations with about six hours of wideband recordings, including "nacchere", were carried out. Signal levels were low, with far animals, on all three stations, not allowing to perform the time delay measurement as planned. Fish finder data show the presence of a reflective (prey field ?) layer, but it was not possible to measure if it was coincident with the depth of feeding dolphins.

NR/V Alliance, a quiet and stable platform for acoustic research, was used to perform a combined acoustic a visual survey in the Ligurian Sea. The cruise was organized in two distinct phases, one for studying the distribution of marine mammals and possibly locating clusters of sperm whales, and one dedicated to finding, tagging and tracking sperm whales (WHOI Project headed by Peter Tyack).
CIBRA provided equipment (towed arrays, wideband hydrophones, recording and analysis equipment, software, sonobuoy receiver) and personnel for both phases.

Two arrays were towed at different depths. The CIBRA array, featuring 2 sensors with 45 kHz bandwidth and low noise, was towed at approximately 25 meters of depth with about 140 meters of cable.
The Saclant URC array, featuring 128 phones to allow high resolution beamforming, was towed at about 80-90 meters of depth with a 400 meters long cable.
It allows real-time beamforming with bandwidth limited to 8kHz for finding and tracking sperm whales (Phase II). It also features modified electronics to provide wide bandwidth (>45 kHz) & low noise on 4 sensors.

Wideband hydrophones (300 kHz) & sonobuoys (20kHz) were used on stations.

2 phones, one from each array, were continuously recorded (1 h cuts) and monitored. Audio files and detections are time- and geo-referenced.

Acoustic classification was performed in real-time in 1 minute time slots. While listening and observing real-time spectrograms, researchers classify received signals 24h/day and fill an acoustic log organized in 1 minute time slots. Each slot is georeferenced to be plotted on a GIS.
Acoustic classification was based on categories tailored on the Mediterranean fauna.

Sightings were performed by a team of 3 observers + 1 recorder

Teams size: 3 for acoustics (CIBRA), 8-12 for sightings (+ spares)

Results

- Striped dolphins (recorded & sighted)
- Common dolphins (recorded & sighted)
- Pilot whales (recorded & sighted)
- Sperm whales (recorded & sighted)
- Unidentified dolphins (recorded; no sightings to assess species)

Equipment assembled for SIRENA 03

The CIBRA array was designed to match the needs of marine mammals' studies. It features 2 sensors with 45 kHz of bandwidth and very low noise. It can be deployed with a small winch, though it can be easily moved, deployed and recovered by hand as well.

Equipment on the NRV Alliance

Wideband towed array (2 channels, 45 kHz bw)
Wideband stationary hydrophones (Saclant URC)
Sound Analysis Network Workstation
- 10 channels, 48 kHz bw each, 600GB storage
- 1 channel, 400 kHz bw

2 Portable PCs with navigation software and real-time GIS (ArcView 8.2)
Wireless network
Radio equipment for GPS-APRS transmission
Radio receiver for sonobuoys

CIBRA Sound Analysis Network Workstation

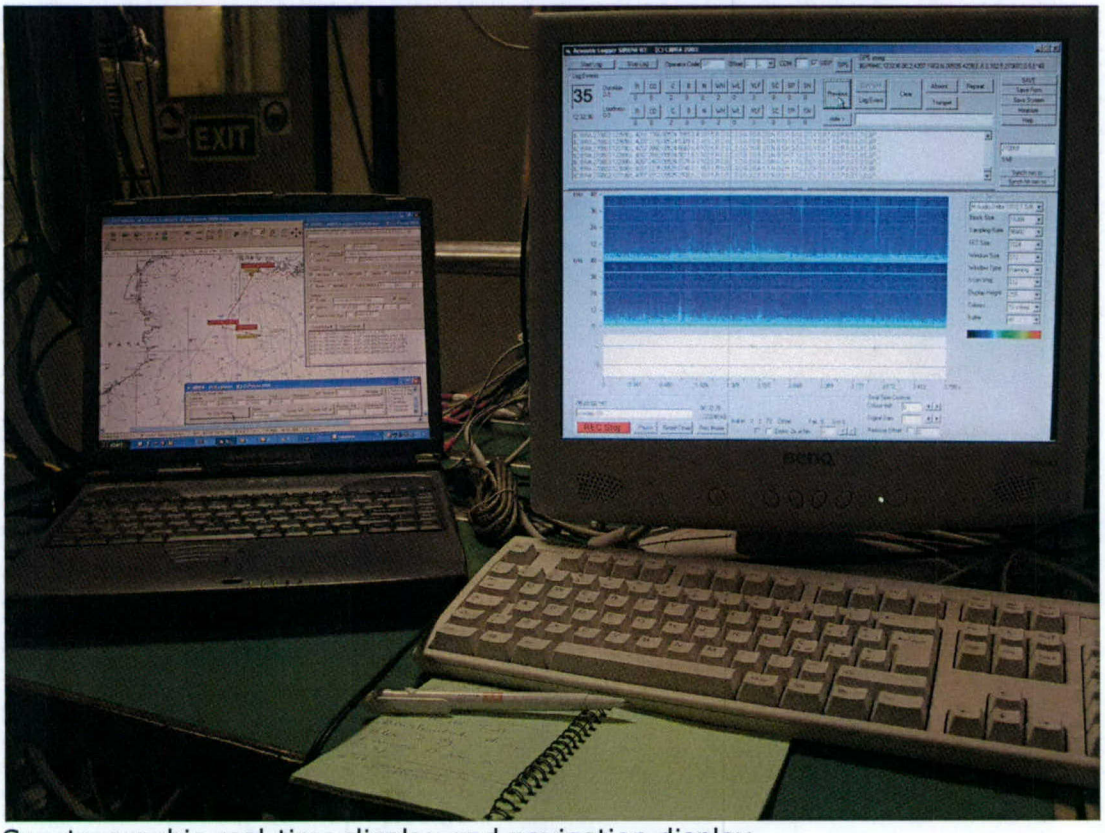
Runs on Win 98/2K/NT/XP
multiple high resolution real-time spectrograms
digital zooming into any frequency band
continuous hard disk recording (1 hour cuts, time and georeferenced)
scheduled hard disk recording
GPS data logging, file georeferencing
Serial NMEA input and NMEA distribution over network (either wired or wireless)
event logging, GIS mapping
multiple display support
devices supported:
ISA & PCI sound boards
laptops' built-in audio
USB & FireWire audio interfaces
optical and electrical digital audio I/O
up to 192k samples/sec with PCI/FireWire interfaces
up to 800k samples/sec with NI DAQ (PCI/FireWire interfaces)
sonobuoy radio-receiver, single channel, 20 kHz bw

Software (developed by CIBRA)

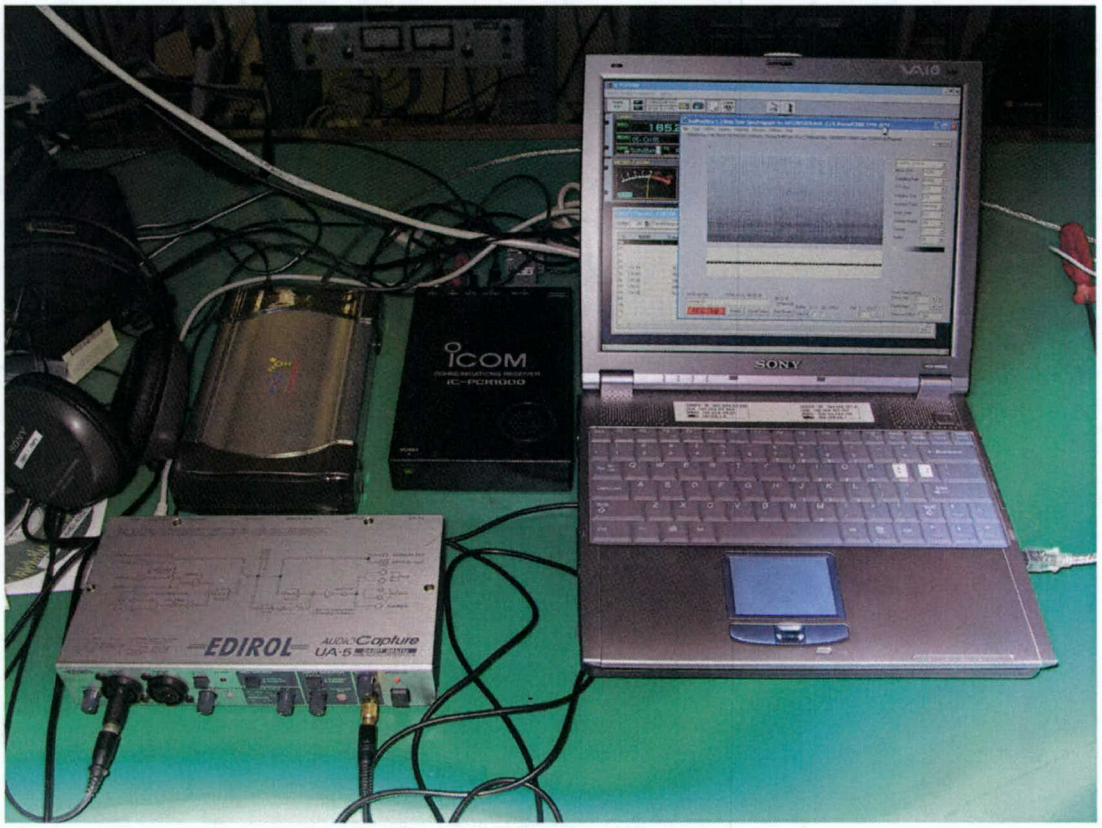
SeaPro	real-time sound analysis, display and recording
SeaProDAQ	real-time sound analysis, display and recording for National Instruments DAQ boards to allow up to 1 MHz sampling
SlotLogger	classification of received signals & distribution of data by UDP; works on 1 minute time slots
EventLogger	software to log acoustic detections and other events
NMEAManager	management of serial NMEA data and broadcast by UDP, conversion of serial to UDP and back
UDPMonitor	display & log UDP messages
OziManager	feed OziExplorer with NMEA data received on UDP port (this module is also integrated in the EventLogger)
ArcUDP	VBA extension to ArcView 8.2 to receive and plot UDP data
WhaleLocator	a software to asses the range of a diving sperm whale according to the delay among clicks received on the direct path and those delayed by surface reflections. It was used assuming a known diving depth based on previous studies.
WhaleSizer	a software to assess in real-time the size of sperm whales by displaying and measuring the Inter Pulse Interval (IPI) computed by means of cepstrum analysis.

Software (thirdy part software)

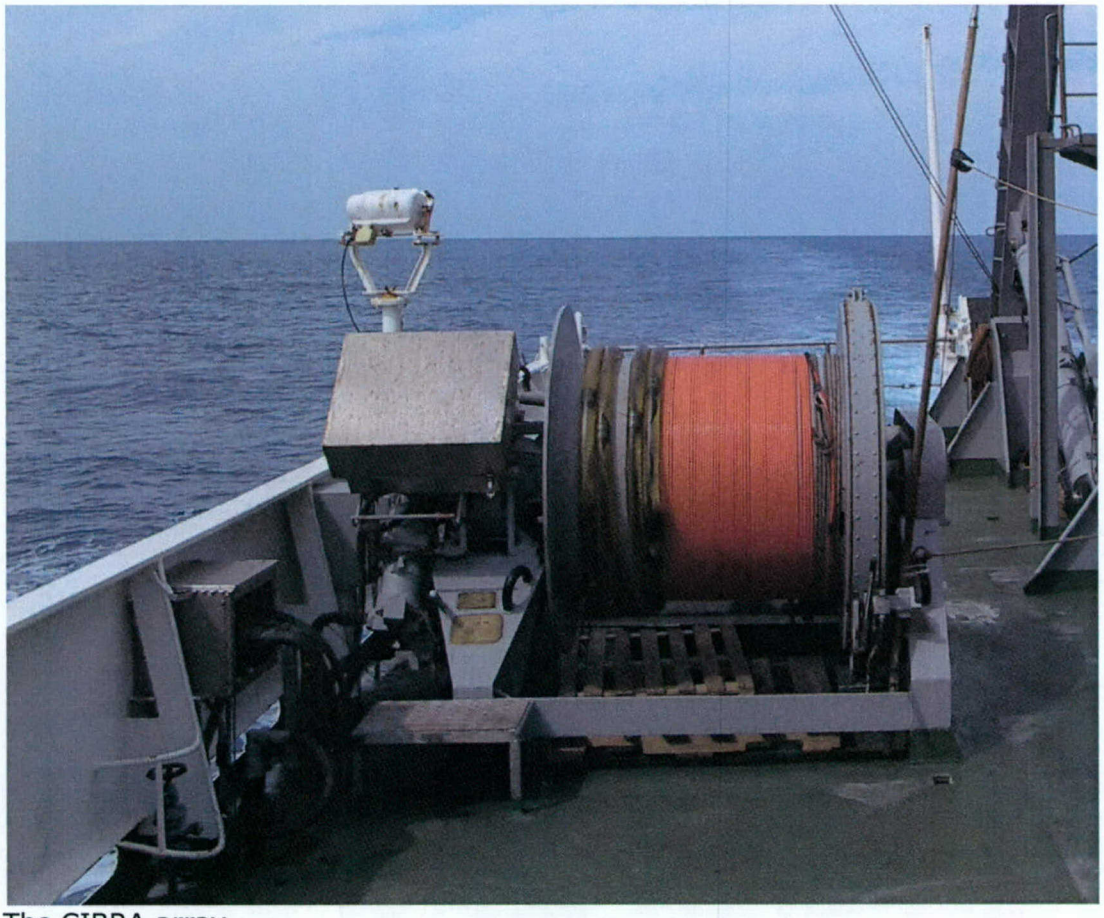
OziExplorer	Navigation and mapping software
ArcView 8.2	GIS



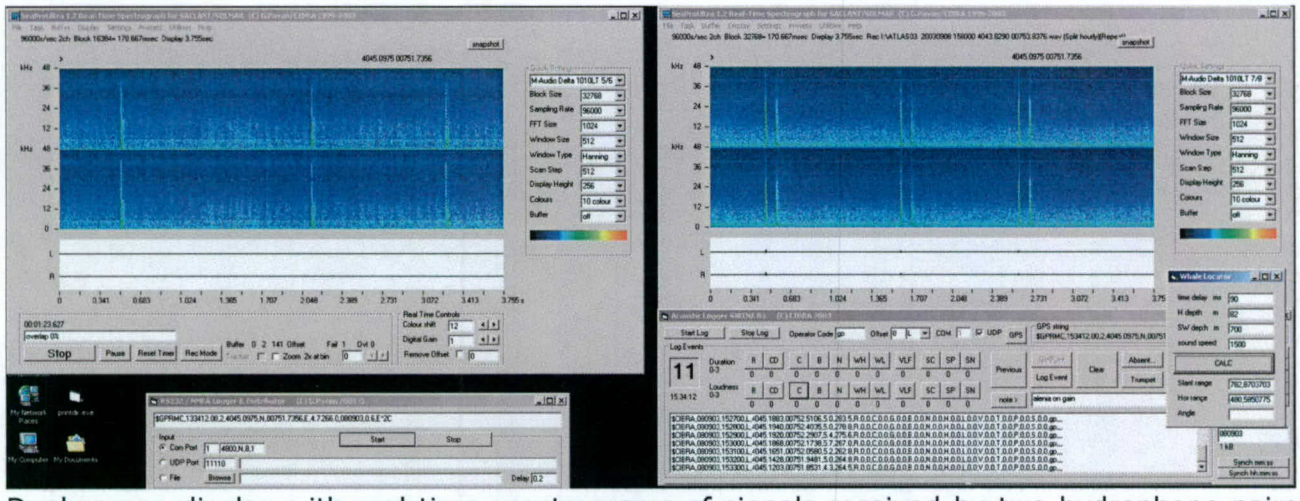
Spectrographic real-time display and navigation display.



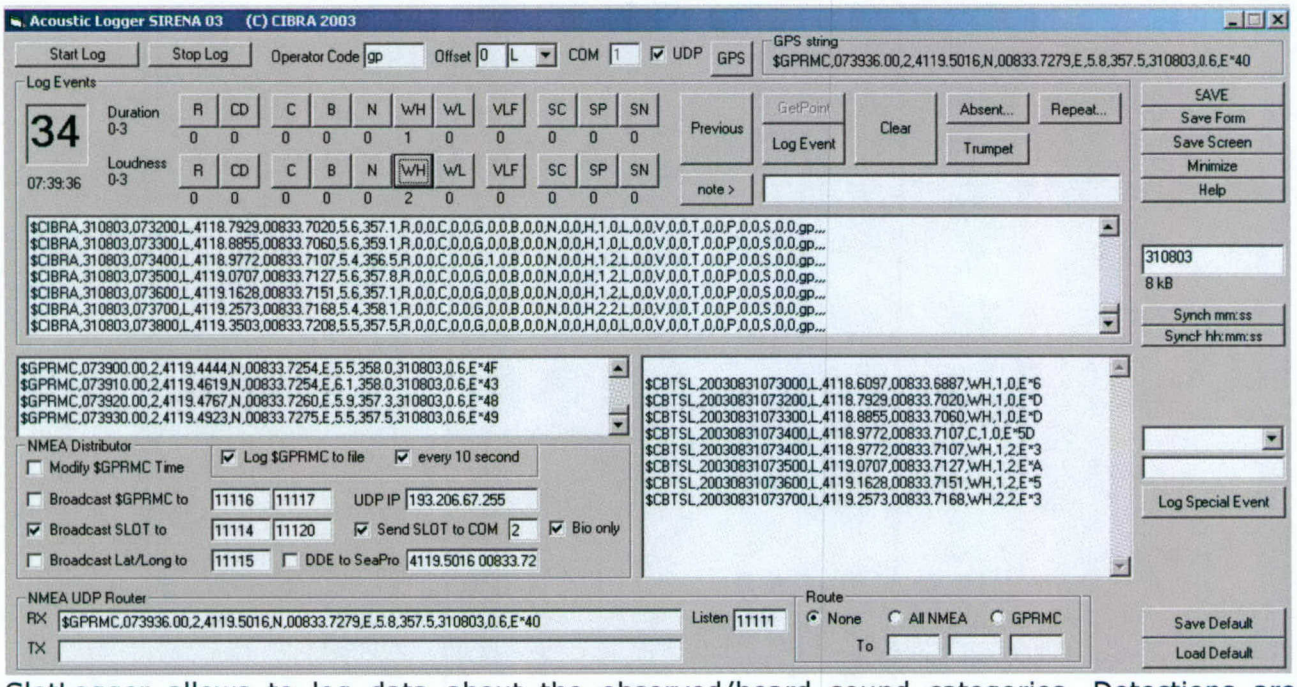
The portable CIBRA workstation with the sonobuoy receiver.



The CIBRA array.



Dual screen display with real-time spectrograms of signals received by two hydrophone pairs (left: shallow CIBRA array; right: deep NURC array).



SlotLogger allows to log data about the observed/heard sound categories. Detections are logged to file and also broadcast by UDP to be processed/displayed by other networked systems. Once setup, only the top panel is shown to the user.

```
$CBTSL,20030831073300,L,4118.8855,00833.7060,WH,1,0,E*D
$CBTSL,20030831073400,L,4118.9772,00833.7107,C,1,0,E*5D
$CBTSL,20030831073400,L,4118.9772,00833.7107,WH,1,2,E*3
$CBTSL,20030831073500,L,4119.0707,00833.7127,WH,1,2,E*A
$CBTSL,20030831073600,L,4119.1628,00833.7151,WH,1,2,E*5
$CBTSL,20030831073700,L,4119.2573,00833.7168,WH,2,2,E*3
$CBTSL,20030831073900,L,4119.4444,00833.7254,WH,1,2,E*1
$CBTSL,20030831074000,L,4119.5405,00833.7269,WH,1,2,E*5
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$CBTSL,20030831074300,L,4119.8192,00833.7390,WH,1,2,E*7
```
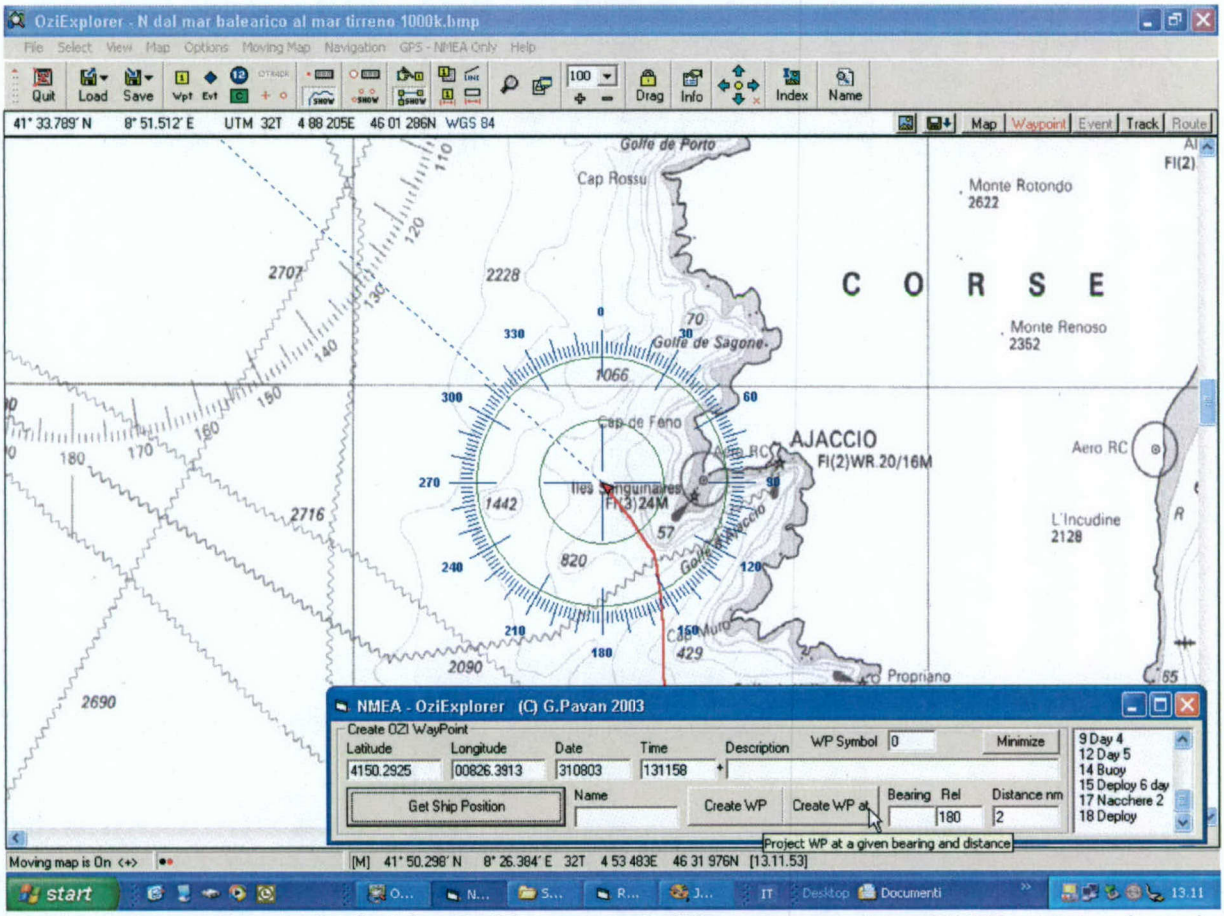
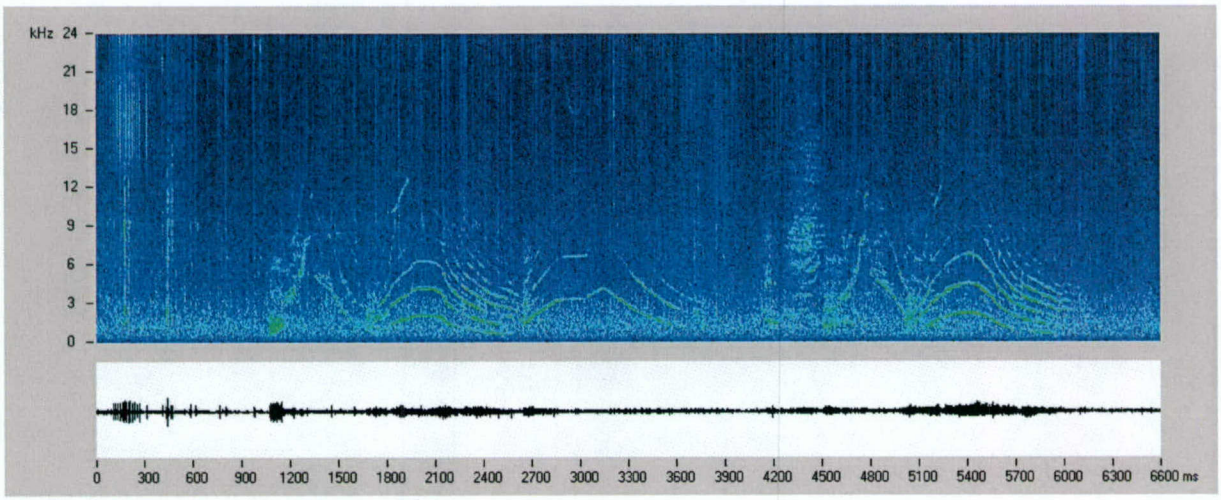

Example of slot detections broadcast by SlotLogger.

```
ATLAS03 20030909 170000 4349.0324 00814.7345.wav # 1382481968 # 2 # 96000 # 01:00:00
ATLAS03 20030909 180000 4347.7012 00818.0802.wav # 1382547504 # 2 # 96000 # 01:00:00
ATLAS03 20030909 190000 4351.2148 00818.3781.wav # 1382481968 # 2 # 96000 # 01:00:00
ATLAS03 20030909 200000 4349.3982 00820.2508.wav # 1382481968 # 2 # 96000 # 01:00:00
ATLAS03 20030909 210000 4352.0663 00821.2562.wav # 1382481968 # 2 # 96000 # 01:00:00
ATLAS03 20030909 220000 4352.6519 00819.6737.wav # 1382481968 # 2 # 96000 # 01:00:00
ATLAS03 20030909 230000 4355.4752 00822.4369.wav # 1382547504 # 2 # 96000 # 01:00:00
```

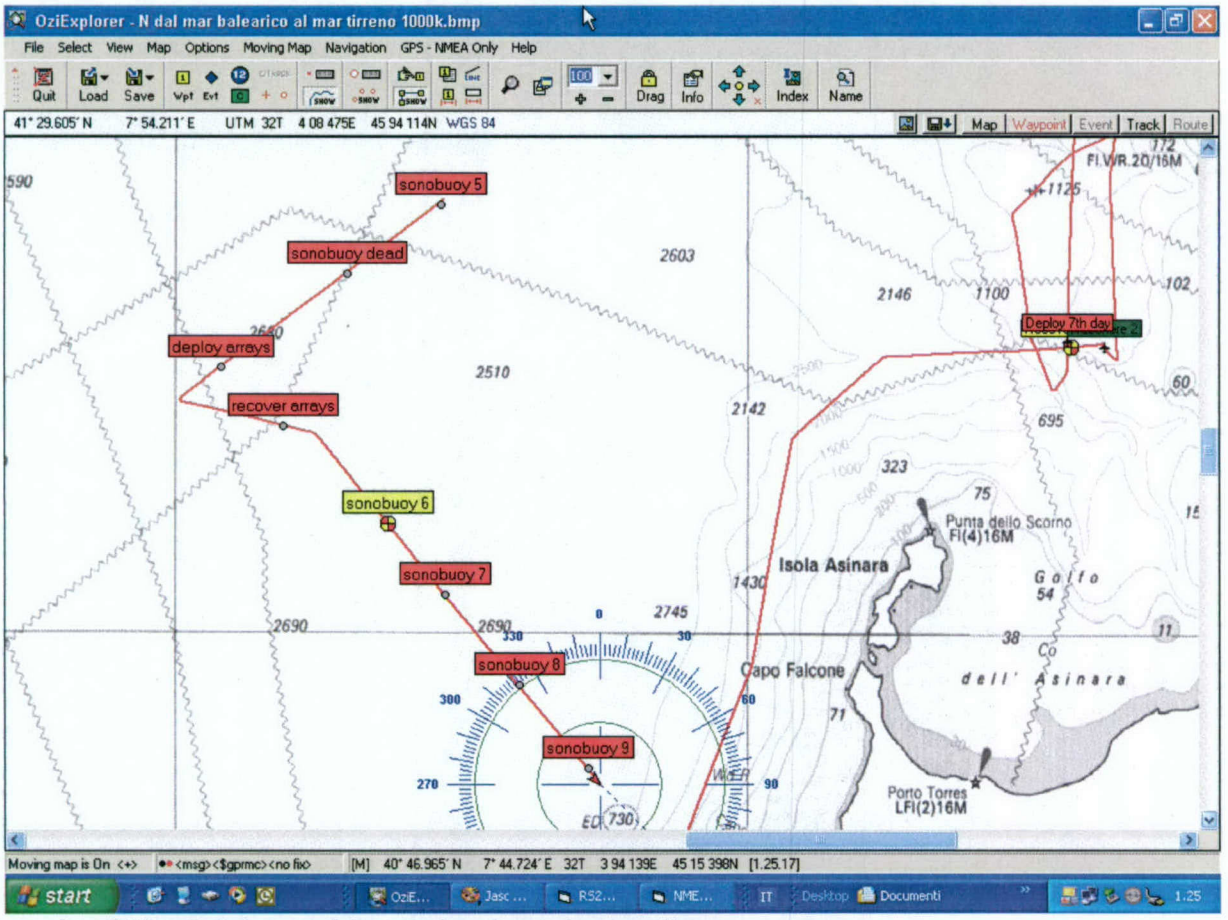
Example of the recordings log. Each file is time and geo-referenced.



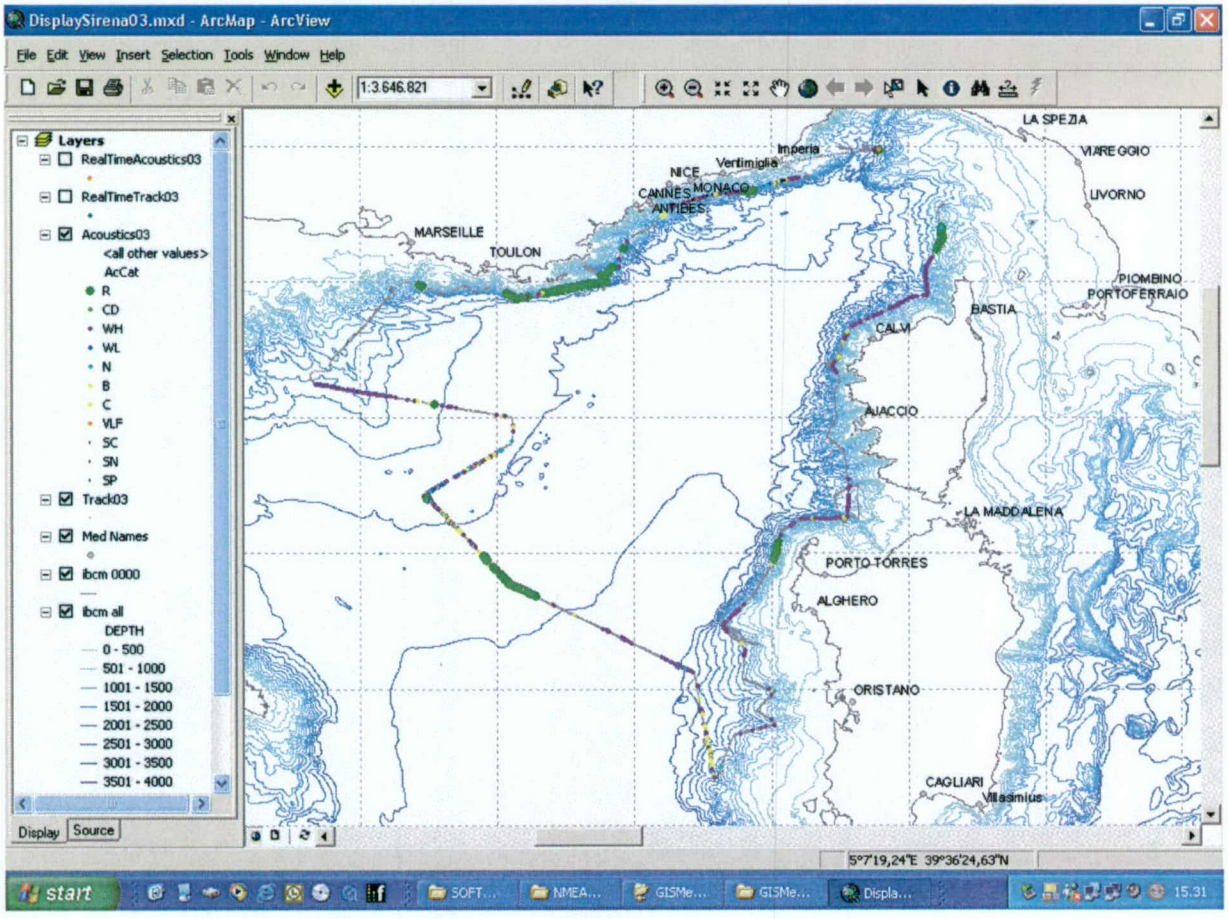
OziExplorer is continuously fed by OziManager; OziManager receives NMEA strings broadcast by NMEAManager and provides the user with an easy interface to log information and place WayPoints on the navigation map.



Pilot whales recorded in Sirena 03.



Example of WayPoints used to mark relevant operations.



GIS map produced in real time in SIRENA03 Phase I. Green dots show acoustic contacts with sperm whales.

CRV Leonardo during Sirena 03 phase II – 03/09 – 11/09

During Sirena 03 phase II CRV Leonardo carried out an oceanographic survey (CTDs and water sampling mainly). This survey was aimed at assessing the conditions in which Cetaceans are sighted or acoustically detected. Visual observations with two to three dedicated skilled persons were carried out.
CIBRA personnel performed recording, monitoring and signal classification with towed array, sonobuoys and stationary hydrophones.

Acoustic and visual results

- Striped dolphins (recorded & sighted)
- Cuvier's beaked whales (sighted)
- Unidentified dolphins (recorded; no sightings to assess species)

Equipment on the CRV Leonardo

Wideband towed array (CIBRA, 4 channels, 60 kHz bw)
Wideband stationary hydrophones (NURC and CIBRA)
Sound Analysis and Recording Workstation (CIBRA)
Radio receiver for sonobuoys (CIBRA)
CIBRA portable Sound Analysis Network Workstation

VULCANO 04

Vulcano '04 was planned in the central south of the Tyrrhenian Sea, at the beginning of spring 2004. It was a rather complex oceanographic campaign, involving three ships. The main campaign goal was to collect oceanographic data on the area, to understand if a "quick assessment procedure" is possible and consistent with reality.

The acoustic activities planned on N/I Galatea during Vulcano '04 trial included three main parts:

1. Wide-band acoustic recording collection during peculiar situations (steep bottom slope and peculiar sightings mainly)
2. Night recording to check for diel patterns in acoustic activity, to possibly confirm the same patterns observed in the Ligurian Sea
3. Acoustic propagation test using an active source playing back biological-like signals.

Bad weather conditions heavily affected the entire campaign, limiting the tasks that could be carried out.

Part 1.
As the ship's main task was oceanographic sampling (CTDs and water sampling), the use of standard programmable sonobuoys was planned. CIBRA radio receiver and real-time signal analysis and recording were used. Out of about 20 hours of sampling, no peculiar signals were detected.

Part 2.
Wide-band CIBRA towed array was planned to be used for this part. Deployment was planned every dawn and recovery every early morning. The system was tested and due to the electrical noise of the ship's environment, was kept running on batteries. Night towing was possible a couple of times only, mainly due to the bad weather. No peculiar signals were detected, while the well known cyclic acoustic activity was confirmed, limited to the sample, in this new study area.

Part 3.
The acoustic propagation trial was aimed at better understanding peculiarities and behaviour of wideband acoustic signals when propagating in deep waters. This is needed to evaluate the animal range in the "real-world" when certain levels are detected at sea.
Two ships were made ready and tested a playback system (176dBs maximum playback level) were one ship would have used the active transducer, and the other would have received the signal using standard hydrophones normally used for acoustic risk mitigation procedures.
Tests were carried out using one ship as the active source and a sonobuoy as a receiver.
The real trial was not possible due to the bad weather conditions, but data resulting from the test form an interesting background needed to plan further experiments.

Software and hardware development

To support the Acoustic Risk Mitigation Policies being developed by many national and international civil and military organizations the PC based Sound Analysis Workstation developed at CIBRA was improved and extensively tested to provide an affordable and flexible tool for wide band acoustic detection and monitoring. It provides detection, processing, storage and plotting capabilities and can be used for both wide area surveys and local monitoring needs.

For Sirena needs improvements were made mostly to the software to allow 1) recording and analyzing sounds received by up to 8 wide band sensors, 2) recording and distributing NMEA navigation data with the ability to convert serial data to UDP data packets to be distributed on standard Ethernet network and converted back to serial whenever required, 4) logging and classification of acoustic contacts, 5) logging visual contacts, 6) sharing data among a network of PCs, 7) plot georeferenced data (ship position, sonobuoys, array deployement, acoustic contacts, visual contacts) on a GIS in real-time.

A significative improvement was made on the data sharing capabilities and on the interface to exchange data with the serial network used on the Alliance to record all acoustic and visual contacts.

The system is modular and flexible to be adapted to different contexts and needs. It can exchange data either on serial lines or on an Ethernet network.

The system requires at least one PC dedicated to sound recording and one to GIS, navigation and data exchange; additional networked PCs can be used to distribute processing and visualization needs.

The workstation was improved by adopting a 8 channels sound acquisition board with 96 kHz sampling rate, extending storage capabilities, and adding a sonobuoy radio receiver.
Depending on the chosen acoustic interface and on storage capabilities, 2 to 8 channels with bandwidth up to 100 kHz can be continuously recorded 24 hours/day. Acoustic data is stored in standard *wav* files, in user defined time cuts; each cut is time- and geo-referenced.

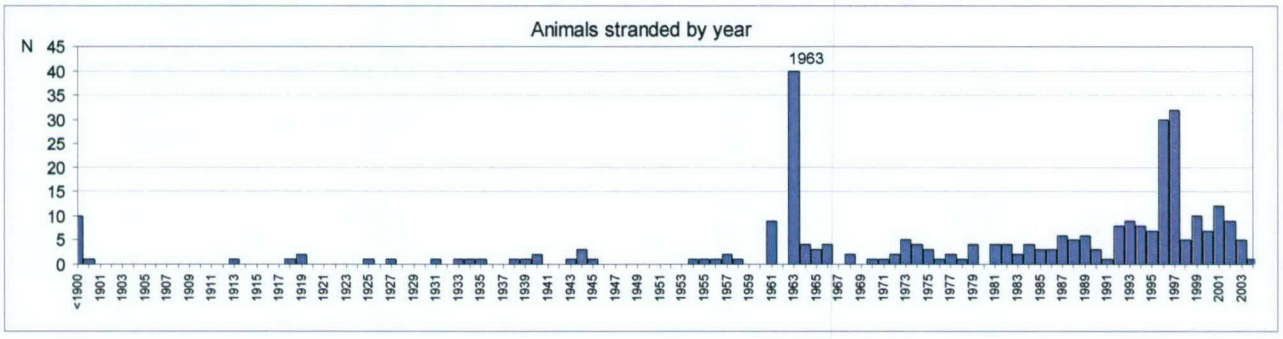
A set of sensors (wideband towed arrays, stationary hydrophones, sonobuoys), either commercial or designed for the purpose, has been also tested to set up a self contained, lightweight, easy to install and use, affordable equipment for passive acoustic research.

Database management

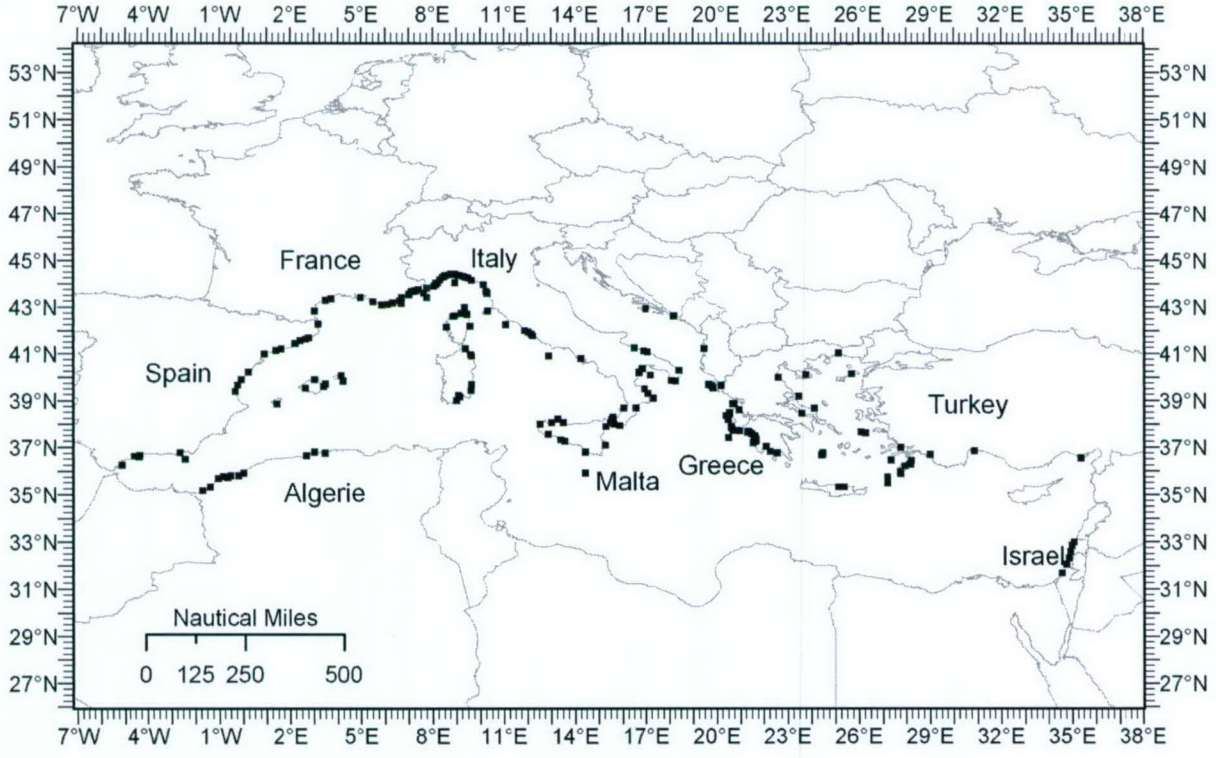
CIBRA supports the development of the SOLMAR Databases, in particular those related with cetacean strandings on the Italian coasts.
The database and GIS of Cuvier's beaked whales strandings in the Mediterranean Sea has been completed in cooperation with the Natural History Museum of Milan, the Centro Studi Cetacei, and SPAWAR (USA) (paper submitted).

Historical Database and GIS of Cuvier's beaked whales' strandings in the Mediterranean Sea

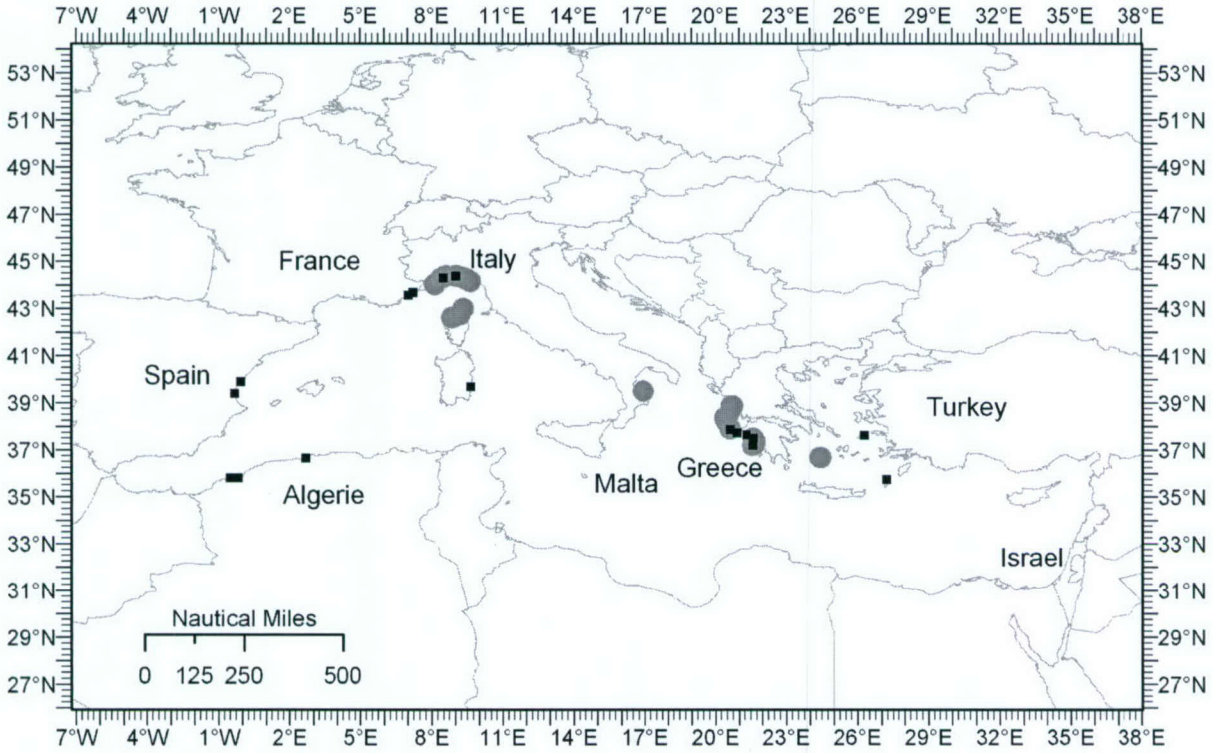
In cooperation with the Italian Stranding Network, managed by Centro Studi Cetacei, with the Natural History Museum of Milan and with SPAWAR (Angela D'Amico, San Diego, US) the database of the Cuvier's beaked whales strandings occurred in the Mediterranean Sea has been completed. The work was based on the collection of original stranding records, published stranding reports, newspapers' articles, data on skeletons in Museums, and any published article containing information about stranded animals.
Results have been presented in two international conferences and the paper describing the work done and our findings has been submitted for publication on the Journal of Cetacean Research and Management. The database will be incorporated in the SOLMAR databases at NURC.



Strandings of *Ziphius cavirostris* by year; peaks in 1963, 1996 and 1997 reveal the occurrence of noteworthy mass strandings.



Strandings of *Ziphius cavirostris* stored in the database (305 animals).



Strandings of *Ziphius cavirostris* (black squares: two animals; gray circles: 3 or more animals).

Acoustic Data Analysis

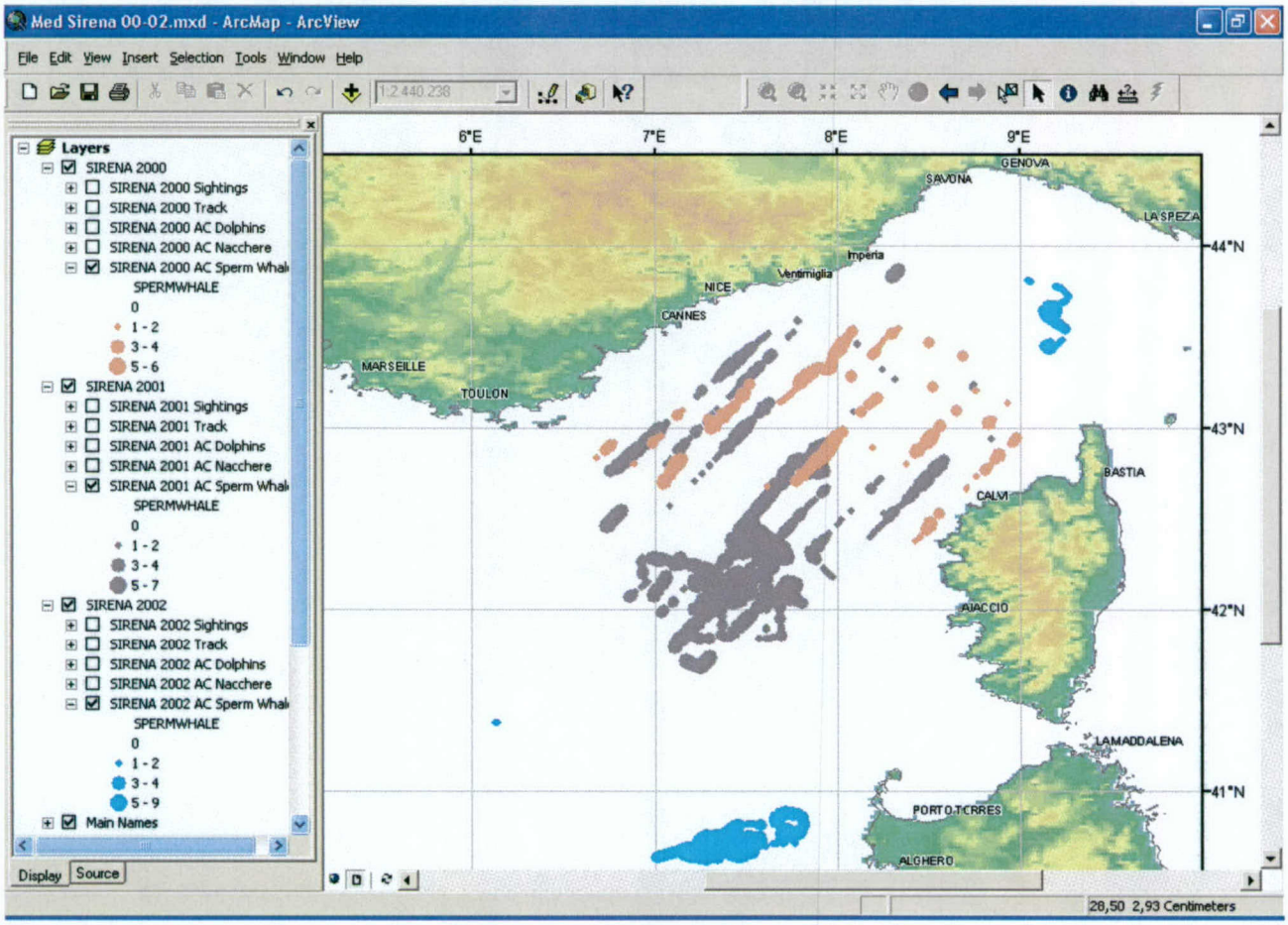
Analysis and comparison of recordings and classification made with the CIBRA Network Workstation in SIRENA 00-01-02 to plot on a GIS the acoustic contacts and compare them with sightings; the most significative results are:

- demonstration of the importance of using wide-band and low-noise equipment to maximize detection capabilities
- demonstration of clear diel cycle in dolphins' vocalization
- higher frequency of acoustic contacts than sightings

(data presented at the Marine Mammals Conference held in Greensboro in December 2003; paper in preparation)

Analysis of recordings (0-90 kHz) made by EARS buoy (NRL-USA), deployed in the Ligurian Sea for 18 days during SIRENA 03, to identify biological sounds.

Analysis of SIRENA 03 recordings and acoustic classification made with the CIBRA Network Workstation (96 kHz sampling, 2 channels from towed arrays and 48 kHz sampling, 1 channel from sonobuoys - totalling 450 GB of acoustic data) to produce a GIS map of acoustic contacts and to compare results with those obtained in previous cruises.



Map showing acoustic contacts with sperm whales in Sirena00 (red), Sirena01 (grey), Sirena02 (blu).

Transfer to hard disks and optical disks of all DAT recordings made by CIBRA in years 1991-1997. The verification of the catalog of recordings and creation of an index are in progress.

Scientific supervision to a whale watching campaign

Aimed at evaluating the results emerging from a comparison between ship embarked observers and plane embarked observers, a summer campaign was supervised and personnel was made available for both platforms.
Results have been compared with acoustic detections made with the EARS buoy deployed in the same area during Sirena 03 cruise (Gobbo et al., 2004; Gobbo, 2004).

INFN NEMO PROJECT

The deployement of the INFN NEMO station (25 km off Catania, Sicily) has been further delayed to January 2005. In 2004 INFN completed the lab that receives the optical cable (deployed in 2003); the cable has been tested and the receiving equipment assembled and tested. The underwater equipment (hydrophones, preamplifiers, AD converters, optical modem) has been tested under pressure and it is now ready for deployement (Riccobene et al., 2003; Riccobene et al., 2004). A dedicated workstation with software developed by CIBRA has been assembled to monitor and record hydrophone data to identify marine mammals signatures and to measure the underwater noise with 48 kHz bandwidth.

Education and dissemination of information

CIBRA organized seminars and other educational activities targeted at students of biology university classes, institutions involved with bioacoustic studies, research groups, and general public.
Courses and seminars focused on four main topics: marine mammals and their behaviour, underwater bioacoustics, analysis and classification of biological sounds, acoustic pollution, field instruments for sound recording and analysis.
Seminars were also made to provide NURC and IT Navy's personnel with basic principles of marine mammal biology and underwater bioacoustics.

Concise summary of accomplishments

Scientific and technical support to NURC in managing the SOLMAR Project (Sirena cruises, databases, development of mitigation policies, public outreach).

Participation to SIRENA cruises to collect acoustic recordings, to support the WHOI tagging project, to test new equipment and to develop and test data sharing protocols.

Creation of a digital sound library for the Mediterranean Sea

Development and testing of equipment and protocols for both acoustic research and mitigation needs.

Support to other organizations concerned with underwater acoustic research (Qinetiq, Columbia University / LDEO, INFN.

Public outreach and education, including contribution to books, websites, cdroms, etc.

Major Problems/Issues in the development of the project

Deviation from previous plans

SIRENA 04 has been cancelled by SACLANT URC
The deployement of the INFN NEMO station, originally planned in summer 2003 has been delayed to January 2005.

Other problems encountered belong to three categories:

financial

the not favourable Dollar/Euro exchange rate reduced the effective amount of money received by about 25% compared to the 1/1 exchange rate and by more than 30% (average) compared with previous grants from US. Compensation was mainly done by reducing equipment development and travels.

weather

During field work most of the problems were related to bad weather conditions. In particular, bad weather severely affected the acoustic monitoring and the sound propagation experiment planned in Vulcano 04 sea trial. In Sirena 03 the "deep nacchere" experiment required very calm sea conditions; unfortunately most stations were cancelled due to sea state and in the few performed tests animals were heard but they were too far from the ship. Also, it was not possible to actively approach the animals because of the time required to deploy/recover the 400 meters long vertical array and the fish finder.

technical

Most technical problems were related with range estimation and accurate localization of vocalizing animals, dolphins in particular, both during surveys and in the implementation of mitigation policies.
On the contrary, localization of sperm whales was very accurate due to the performances of the real-time beamformer available on the NRV Alliance.
To possibly solve these problems it is envisable the development of a lightweight affordable wideband array with a pair of well spaced sensors (20-40 meters) and with a short array for wideband beamforming capabilities selectable in the octaves 8-16-32 or 10-20-40 kHz.

Publications

Peer-Reviewed Journal Articles

FOSSATI C., MANGHI M., PAVAN G., PRIANO M., 2003. Stima acustica della crescita di un capodoglio (*Physeter macrocephalus* Linneaus, 1758) ricatturato in Mar Ligure. Atti Soc. it. Sci. nat. Museo civ. Stor. nat. Milano, 144 (I): 75-81.

RICCOBENE G., COSENTINO L., MUSUMECI M., PAVAN G., SPEZIALE F., 2004. Acoustic detection of UHE neutrinos: a station for measurement of the deep sea acoustic noise. Nuclear Instruments and Methods in Physics Research A 518 (2004): 220–222.

PAVAN G., FOSSATI C., MANGHI M., PRIANO M., 2004. Passive acoustics tools for the implementation of Acoustic Risk Mitigation Policies. In "Proceedings of the workshop on Active sonar and cetaceans", 17th ECS Conference, March 2003, P. G. H. Evans and L. A. Miller Eds., EUROPEAN CETACEAN SOCIETY NEWSLETTER NO. 42 – SPECIAL ISSUE: 52-58.

Books or Chapters

Contributes (texts, spectrograms, photographs and sound files) were given to:

Whale Almanac, editor Marije L. Siemensma, 48 pages, Leiden 2004, spin-off of the Europhlukes project 2001-2004, which was coordinated by the Leiden University Institute of Environmental Sciences (CML).

McCarthy E., 2004. International Regulation Of Underwater Sound: Establishing Rules And Standards To Address Ocean Noise Pollution. Kluwer Academic Publ.: 287pp.

Peter Wille, 2005. Sound Images of the Ocean in Research and Monitoring. With CD. Springer Verlag. In Press.

Official website of the SOLMAR Project: http://solmar.nurc.nato.int

Technical Reports (Non-Refereed Publications)

G.RICCOBENE, L.COSENTINO, G.PAVAN, S.PRIVITERA, F.SPEZIALE.
A deep sea station for measurement of acoustic noise at the NEMO test-site. INFN-LNS Report 2003.

In press

Pavan G., Podesta M., D'Amico A., Portunato N., Fossati C., Manghi M., Priano M., Quero M., Teloni V. - A GIS and associated database for the Italian Stranding Network. A cooperative project based on GIS technologies. European Research on Cetaceans, 16.

Manghi M., Pavan G., Fossati C., Priano M. - Mapping and analyzing acoustic surveys' results: a GIS approach. European Research on Cetaceans, 16.

Fossati C., Manghi M., Pavan G., Priano M. - Dual use technology on cetacean research in the Mediterranean Sea: wide area aerial surveys with audio recordings from air-launched sonobuoys. European Research on Cetaceans, 17.

Manghi M., Fossati C., Pavan G., Priano M. - Diel occurrence of characteristic acoustic emission in feeding striped dolphins. European Research on Cetaceans, 17.

R. Gobbo, M. Manghi, R. Trucchi - Aerial and surface cetacean survey. An efficiency comparison during a seasonal whale-watching activity in the Mediterranean Sea.

PODESTA' M., D'AMICO A., PAVAN G., DROUGA A., KOMNENOU A., PORTUNATO N.; A Review of *Ziphius* cavirostris Strandings in the Mediterranean Sea. Submitted

Abstracts

Pavan G., Fossati C., Manghi M., Priano M., Nacchere: an acoustic behavior of striped dolphins. European Research on Cetaceans, 17. Abstract.

Priano M., Pavan G., Fossati C., Manghi M.; Sound Analysis Workstation for the implementation of Acoustic Risk Mitigation Policies. European Research on Cetaceans, 17. Abstract

Podesta', M., A. D'Amico, G. Pavan, A. Drouga, A. Komnenou and N. Portunato; A Review of *Ziphius* cavirostris Strandings in the Mediterranean Sea. European Research on Cetaceans, 17. Abstract.

Conference presentations

Frontier detectors for frontier physics - 9th pisa meeting on advanced detectors - May 25-31, 2003, La biodola, Isola d'Elba, Italy
G.Riccobene, L.Cosentino, G.Pavan, S.Privitera, F.Speziale; A DEEP SEA STATION FOR MEASUREMENT OF ACOUSTIC NOISE AT THE NEMO TEST-SITE.

Convegno della Società Italiana di Teriologia, Riccione, 6-9 novembre 2003
Pavan G., Podestà M.; Progetti di ricerca per lo studio e la tutela dei Cetacei del Mediterraneo. Talk.

Mare e salute, Pavia, 22 novembre 2003
Pavan G., Research and conservation on marine mammals of the Mediterranean Sea. Talk

15th Biennial Conference on the Biology of Marine Mammals, Greensboro, NC (USA), December 2003
Pavan G., Fossati C., Manghi M., Podestà M. , and Priano M.; Three years of visual and acoustic surveys in the Ligurian Sea. A GIS approach to data analysis and visualization. Talk.

18th ECS Conference, Sweden, March 2004
Pavan G. Talk in the G0 Workshop.
Pavan G. Hardware and software tools for acoustic and visual surveys. Poster

MMC-JNNC Workshop, London, 28-30 settembre 2004-10-21
Pavan G., Manghi M.; Tools for underwater noise monitoring, marine mammals' surveys, and acoustic risk mitigation policies' implementation. Poster

Other references

Smultea, M.A., M. Holst, W.R. Koski, and S. Stoltz. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic program in the Southeast Caribbean Sea and adjacent Atlantic Ocean, April–June 2004. LGL Rep. TA2822-26. Rep. From LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 106 p.

Gobbo R., 2004. Applicazione e comparazione di tecniche acustiche e visuali nello studio della cetofauna del Mar Ligure Occidentale. Tesi di Laurea in Scienze Biologiche, Università di Padova. Supervisor Dr. Gianni Pavan

Technology Transfer

CIBRA provides consultancy for many research organization and for governative agencies. When requested it also provides education and training for the personnel to be involved in activities concerned with marine mammals and acoustics in particular.

Hardware & Software

The sound analysis software was provided to many researchers all around the world and it has been also adopted for a course at the University of Bangor (Wales, UK).

CIBRA activities frequently require special instruments and often CIBRA is requested to design equipment for other organizations. In both cases it is needed to cooperate with companies or individual experts to find the right solution either based on off the shelf equipment or on custom designs that may require long experimentation and testing. The Nauta-rcs company is the CIBRA interface for these operations and for eventually marketing final products. Either directly or through Nauta-rcs services, CIBRA cooperates with many companies to "tune" the development of their instruments or to get help in developing its own equipment.

Nauta-rcs, with the scientific support of CIBRA, is becoming one of the reference Italian companies for the furniture of off the shelf audio components well suited for scientific use in the underwater acoustic field as well as in the design of custom solutions. It also has the representative for Europe of the hydrophones produced by Cetacean Research Technology that is a small company based in Seattle (USA).

Two complete detection systems (towed array with complimentary electronics and sound analysis workstation) have been developed for GreenPeace in cooperation with Nauta-rcs.

Future plans include the production of a complete workstation (sensors+processing), based on the concepts developed in the CIBRA Sound Analysis Network Workstation, tuned for the implementation of risk mitigation policies in seismic surveys. The most difficult issues to be solved are those related with the coding of information to be shown to operators to maximize their ability to detect animal calls that vary from infrasounds to ultrasounds and to reliably and easily estimate the range of the emitters. For this project a PC based real-time wideband beamformer has been developed and tested, but it is required to get funding to design and build a matching array of hydrophones.

CIBRA participated in the design of an underwater platform to be deployed in summer 2004 (two years delay) by INFN (Istituto Nazionale di Fisica Nucleare) 25 km off Catania (Sicily). The platform, placed at 2500m depth, transmits wideband (48 kHz) acoustic data collected by 4 phones to INFN laboratories through an optical cable. CIBRA designed and developed the software for data acquisition and display.

An interesting and hopefully promising partnership has been recently established with the University of Pisa to develop a prototype of a completely optical array. Optical hydrophones has been already produced and tested. In one year it should be possible to have prototypes to be adapted and tested for different needs.

Sound library

Sound samples and sound spectrograms about marine mammals and about anthropogenic noise have been provided for two books being published in late 2004.

Sound samples have been also provided to the "Parco Le Navi" (Cattolica, Italy) to set up a scientific exhibit on the "Sounds of the Sea" that includes a room dedicated to the noise pollution.

CIBRA participates in the publication of a CD-ROM on marine mammals of the Mediterranean Sea in cooperation with Centro Studi Cetacei, that manages the Italian Stranding Network, and the Marine Mammals Tissue Bank of the University of Padoa. The CD-ROM will include sound samples and video clips. (Publication date 3Q 2004)

Awards/Honors/Invention Disclosure

n/a

Patents Submitted

n/a

Patents Issued

n/a

Other Funding and Sponsored Work

Data entry and elaboration for an oceanographic GIS for marine mammals' studies.
(co-funded by University of Venice for academic year 2003-2004).

CIBRA participates in the design of an underwater platform to be deployed in January 2005 (two years delay) by INFN (Istituto Nazionale di Fisica Nucleare) 25 km off Catania (Sicily). The platform, placed at 2500m depth, will transmit wideband (48 kHz) acoustic data collected by 4 phones to INFN laboratories through an optical cable. (NOT FUNDED – reimbursement of travel costs only)

Cooperation with the Italian Stranding Network managed by Centro Studi Cetacei (NOT FUNDED).

Vulcano 04 participation was partially funded by NURC.

Flight time during the whale-watching campaign in the Ligurian Sea was funded by Coop. Battellieri and WWF – Liguria.

Participation to seismic surveys was funded (personnel salary and travel costs) by Columbia University / LDEO.

Participation to the MMC workshop in London (September 2004) was granted by MMC.

PROCEEDINGS OF THE WORKSHOP ON

ACTIVE SONAR AND CETACEANS

Held at the
European Cetacean Society's 17th Annual Conference,
Auditorio Alfredo Kraus, Las Palmas, Gran Canaria, 8th March 2003

Editors:

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PASSIVE ACOUSTIC TOOLS FOR THE IMPLEMENTATION OF ACOUSTIC RISK MITIGATION POLICIES

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INTRODUCTION The effect of anthropogenic noise on the marine environment is a serious concern for scientists (Richardson *et al.*, 1995; Nascetti *et al.*, 1997; D'Amico, 1998; Frantzis, 1998; AA.VV, 2003) and has gained the attention of public opinion. To reduce the impact of high power underwater sound sources, Acoustic Risk Mitigation Policies have been drawn up and are currently under implementation. Basically, ARMP are aimed at preserving particularly populated areas and critical habitats, and at reducing or stopping emissions if animals are within a defined distance.

Among tested approaches, passive acoustics has shown to be an efficient tool to (a) expand knowledge about marine mammal distribution in space and time (i.e. with surveys), (b) characterise biological and artificial sources, (c) evaluate effects of sound exposure on animals' behaviour, and (d) monitor, detect, locate and track vocalising animals within, or approaching, a sound exposure area.

Passive acoustics can continuously work regardless of weather, visibility, daylight or night. Sounds efficiently propagating in the water are received from great distances, and all detections can be proved with recordings.

Currently available signal detection and storage equipment allow weeks of recordings from multiple sensors (Pavan *et al.*, 2001; Priano *et al.*, in press). On the other hand, no tools are available for effortless cataloguing of acoustic events, nor for specific signal automatic recognition. Moreover, no definitive methods exist to predict or determine, with high confidence, whether marine mammals are present in a given area or not. In particular, passive acoustics may fail in detecting animals whose vocalisations (class of emissions, emission rates and cycles) are not well known or completely unknown.

To get an overall picture of an area it is thus very important to integrate more methods including visual sightings, aerial surveys and any new technology aimed at detecting surfacing and diving animals (infrared detection, radar detection, low power active sonars).

Many "Dual Use" experiments, even if they have offered excellent results in the low frequency band, have clearly shown that specific equipment packages are needed to satisfy mitigation peculiarities. Expanded bandwidth, very low self noise, easy to use interfaces, optimised for rapidly time-varying signals, are the striking points of the required ARMP tools.

The CIBRA Workstation Since 1999, CIBRA has been co-operating with SACLANT Undersea Research Centre in the SOLMAR project (Sound, Oceanography and Living Marine Resources). The project is aimed at developing Marine Mammals Risk Mitigation policies (MMRM) for NATO Navies and at defining and testing the required tools and protocols. To support this project, a PC based Sound Analysis Workstation was designed, assembled and extensively

tested in SIRENA cruises organized by SACLANT (Figs. 1-3). It offers an affordable and flexible tool for wide-band acoustic detection and monitoring. Based on bioacoustic analysis experiences started in the 80s', it was redesigned and updated to match underwater bioacoustics and acoustical oceanography needs (Pavan *et al.*, 1997; Pavan *et al.*, 2001; Priano *et al.*, in press).

Custom-made wideband sensors and arrays feed the analysis system with signals describing the acoustic environment. Arrays operating at different depths (Fig. 1), signals gathered by a sensor network (i.e. sonobuoys), and wideband beam-forming are the explored hardware solutions to get improved, multichannel detection capabilities.

Extended bandwidth is required to preserve ultrasonic signals, including echolocation clicks, that are usually not detected with audio equipment (Fig. 4). Detecting signals whose energy is mostly in the ultrasonic range maximises detection abilities at short range, i.e. within the most sensitive area for MMRM policies. Experience shows that ultrasonic signals can often be the only signals revealing the presence of animals at short range.

Based on the same multi-year experience, an observation protocol has been developed to deal with the circadian patterns of vocalising animals. By continuous monitoring, 24hours/day, it is possible to reveal the presence of animals sporadically vocalising. Also, continuous monitoring while performing sonar emissions, or other possibly invasive actions, is required to detect acoustic responses of animals or any change in vocalising behaviour.

The Workstation is carefully assembled with off-the-shelf components deriving from both high-end audio and industrial signal acquisition; the basic configuration has 8 input channels with 48 kHz bandwidth per channel. Advanced configurations offer up to 12 channels at 96 kHz and up to 400 kHz on a single channel.

The tested sensors configuration consists of a two channel towed array (Fig. 2), designed in 1993 (Pavan and Borsani, 1997), characterised by very low self-noise and 45 kHz bandwidth, and other arrays with assorted sensors ranging up to 300 kHz in frequency (Cetacean Research Technology). A compact array that provides more than 100 kHz bandwidth, with beamforming capabilities up to 20 kHz, is going to be assembled.

The software and the user interface were designed to return easy interaction, real-time feedback and reliability. The software set provides hard-disk recording, together with real-time high-resolution spectrographic and beamformer display. GPS and navigation data logging, operator-based acoustic classification logger, GIS file output as well as acoustic file analysis and post-processing (Fig. 3, 4 and 5) are included. The workstation can provide uninterrupted high resolution monitoring and recording for days. When based on a laptop PC, the system can be installed and operated from small platforms.

To offer continuous recording for days or weeks, required in wide area surveys, signals can be recorded on almost any fast digital storage system. Files are organised in user defined time cuts, georeferenced by automatic GPS logging. Navigation data and georeferenced acoustic events, categorised by trained operators, and can be sent to a GIS for a nearly-real-time mapping (Manghi *et al.*, a, in press). The workstation returns an immediate summary of the underwater acoustic environment.

Maps showing where and when each sound category was detected can be easily plotted (Fig. 5). Useful during the surveys, to get a picture of the detections, this tool reduces the post processing

time. The tables and maps of acoustic contacts can be used as an index to focus the post-processing on those slots and areas containing interesting data. Matching these GIS data with environmental parameters, either derived by remote sensing or oceanographic models, offers exciting possibilities in the study of the distribution of animals.

The described system was tested during SIRENA cruises on the NR/V Alliance (SACLANTCEN CD27/99; CD41/00; CD53/01; CD60/02). The cruises were aimed at performing acoustic experiments and a combined visual and acoustic survey in the Ligurian Sea, Italy. In Sirena 00-01-02, more than 700 hours of passive acoustic monitoring and recording were carried out with wideband towed arrays during 54 research days. State of the art maps of marine mammal distribution resulted from this work (work in progress).

The analysis, based on sound categories detected in 1 minute time slots, show that dolphin vocalisations have a clear diel cycle with higher activity at night: in Sirena 02 (Fig. 6), in the sunset-sunrise interval, slots with detections were up to 80%, four times more than in daylight hours; the same interval contained 84.5% of the slots with "nacchere", a peculiar category of dolphin vocalisations.

Resulting data clearly show that to get a real picture of the presence of dolphins in an area, it is important to investigate on a complete diel cycle. Based on acoustic detections, dolphins, mostly represented by striped dolphins (a pelagic species), were distributed throughout the entire study area. The comparison with sightings shows that the acoustic approach outperformed the visual one; in the specific environment and context of the Ligurian basin, dolphin sightings averaged less than 0.4 per hour.

CONCLUSIONS A multi-sensor approach allows one to monitor many frequencies and depths at once. Large bandwidth allows one to detect ultrasonic signals, including echolocation clicks, that cannot be detected with traditional audio equipment and which can be the only signals revealing the presence of animals. Silent animals, or species whose repertoires are unknown, require this surveillance to be integrated with other approaches including visual sightings, aerial surveys, and any new technology aimed at detecting surfacing and diving.

To make Acoustic Risk Mitigation Policies, Rapid Environmental Assessment and (bio)acoustic research easy, efficient and affordable it is important to rely on:

- compact, easy to use packages including a wideband towed array connected to a wide-band real-time analysis system with possibly beam-forming capabilities
- analysis workstations to monitor multiple sensors at the same time
- a quiet platform
- trained, skilled and motivated operators following tested protocols
- operator based and computer assisted detection tools to provide acoustic classification and early alerting
- 24h/day monitoring to provide reliable data for assessing animals' presence and distribution
- tools to integrate navigation data, sightings, acoustic detections and oceanographic data into a GIS
- an integrated multidisciplinary approach.

The software package and the equipment developed at CIBRA proved to be a flexible and useful tool for both research and mitigation purposes. The sound analysis software can be downloaded from the CIBRA website.

ACKNOWLEDGEMENTS Project carried out within the SACLANT Undersea Research Center's SOLMAR Project with ONR Grants N00014-99-1-0709 and N00014-02-1-0333. The development of the first CIBRA wideband array was granted by the Italian Ministry of the Environment in 1993. We wish to thank the Italian Navy and Adm. Dino Nascetti for the support given to our activities since 1995; Angela D'Amico, Mike Carron and Nicola Portunato for their precious, friendly support during SACLANT U.R.C. activities.

REFERENCES

AA.VV. 2003. *Ocean Noise and Marine Mammals*. The National Academies Press, Washington. 206pp.

D'Amico, A. (Editor), 1998. Saclantcen Bioacoustics Panel. *Saclantcen Report* M-133.

Frantzis, A., 1998. Does acoustic testing strand whales? *Nature* (Lond.), 392:28.

Manghi, M., Pavan, G., Fossati, C., Priano, M., Mapping and analyzing acoustic surveys' results: a GIS approach. *European Research on Cetaceans,* 16: in press (a)

Manghi, M., Fossati, C., Pavan, G., Priano, M., Diel occurrence of characteristic acoustic emission in feeding striped dolphins. *European Research on Cetaceans*, 17: in press (b)

Nascetti, P., Perazzi, A., Hastrup, O., 1997. An investigation of the interaction between active sonar operations and marine mammals. *European Research on Cetaceans*, 10: 61-67.

Pavan, G. and Borsani, J.F. 1997. Bioacoustic research on cetaceans in the Mediterranean Sea. *Mar. Fresh. Behav. Physiol.*, 30: 99-123.

Pavan, G., Priano, M., Manghi, M., and Fossati, C. 1997. Software tools for real-time IPI measurements on sperm whale sounds. *Proc. I.O.A., Univ. Of Loughborough, UK,* 19 (9): 157-164.

Pavan, G., Fossati, C., Manghi, M., and Priano, M. Nacchere: an acoustic behaviour of striped dolphins. *European Research on Cetaceans*, 17: in press.

Pavan, G., Manghi, M., and Fossati, C., 2001. Software and hardware sound analysis tools for field work. *Proc. 2nd Symposium on Underwater Bio-sonar and Bioacoustic Systems. Proc. I.O.A., Vol. 23 (part 4):* 175-183.

Priano, M., Pavan, G., Manghi, M., Fossati, C., Sound analysis workstation for the implementation of acoustic risk mitigation policies. *European research on Cetaceans*, 17: in press.

Richardson, W.J., Greene, C.R. Jr., Malme, C.I., Thomson, D.H., 1995. *Marine mammals and noise*. Academic Press, London. 546pp..

SACLANTCEN CD27, 1999. SIRENA 99 Report. SACLANT Undersea Research Centre, Viale San Bartolomeo 400, 19138 La Spezia, Italy.

SACLANTCEN CD41, 2000. SIRENA 00 Report. SACLANT Undersea Research Centre, Viale San Bartolomeo 400, 19138 La Spezia, Italy.

SACLANTCEN CD53, 2001. SIRENA 01 Report. SACLANT Undersea Research Centre, Viale San Bartolomeo 400, 19138 La Spezia, Italy.

SACLANTCEN CD60, 2002. SIRENA 02 Report. SACLANT Undersea Research Centre, Viale San Bartolomeo 400, 19138 La Spezia, Italy.

WEB REFERENCES

CIBRA http://www.unipv.it/cibra
ONR http://www.onr.navy.mil
SOLMAR http://solmar.saclantc.nato.int

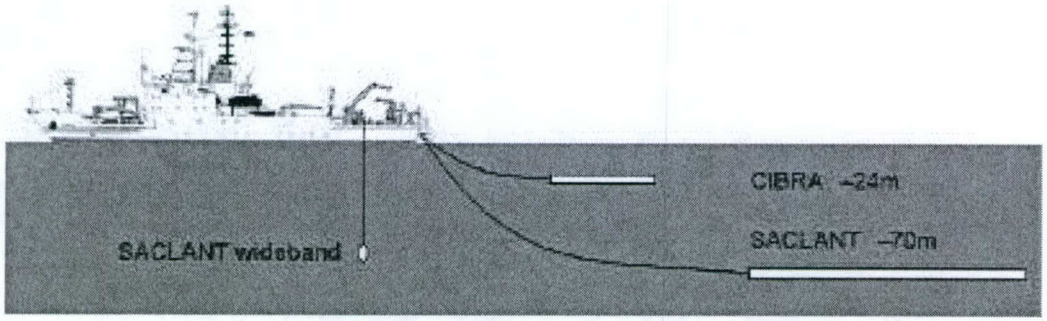

Fig. 1. Multi-sensor configuration allows to maximise detection capabilities. During Sirena 2002 research cruise, two wide-band arrays were towed at different depths. A wideband hydrophone was used in stationary monitoring stations. Sonobuoys were also deployed when cruising at high speed.

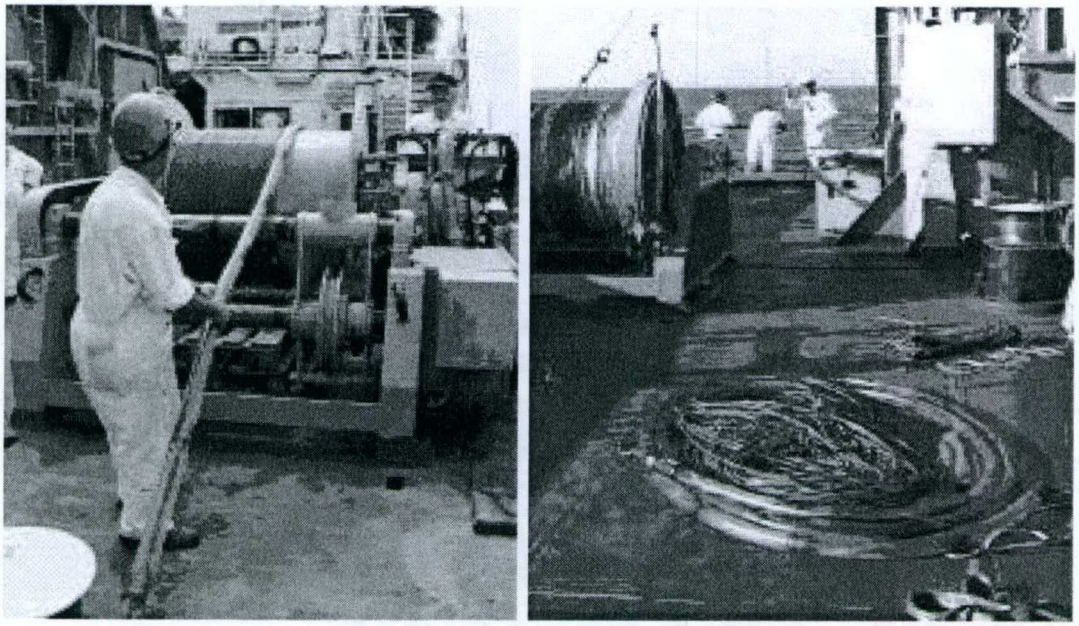

Fig. 2. CIBRA arrays were designed to fit the needs of bioacoustic research in the field. They can be used with a small winch, though they can be easily moved, deployed and recovered by hand as well.

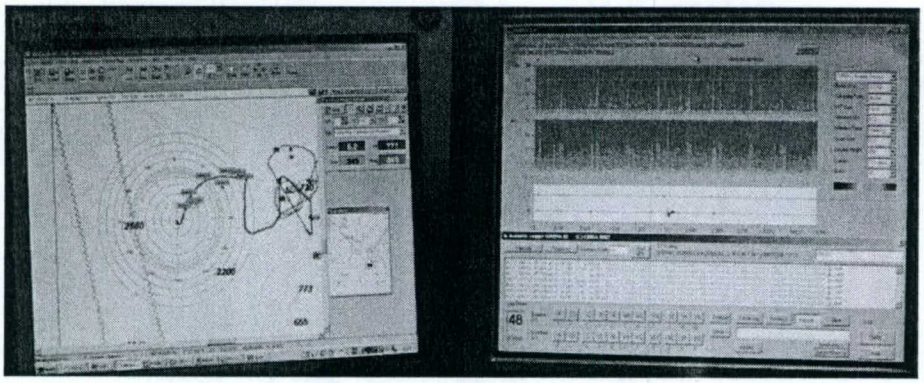

Fig. 3. While listening and observing real-time spectrograms, researchers classify received signals 24h/day and fill a log with 1 minute time slots. Each slot is geo-referenced, allowing a direct link to a GIS for acoustic mapping. On a dual screen system, recording, analysis, display and GIS plotting can be performed at the same time.

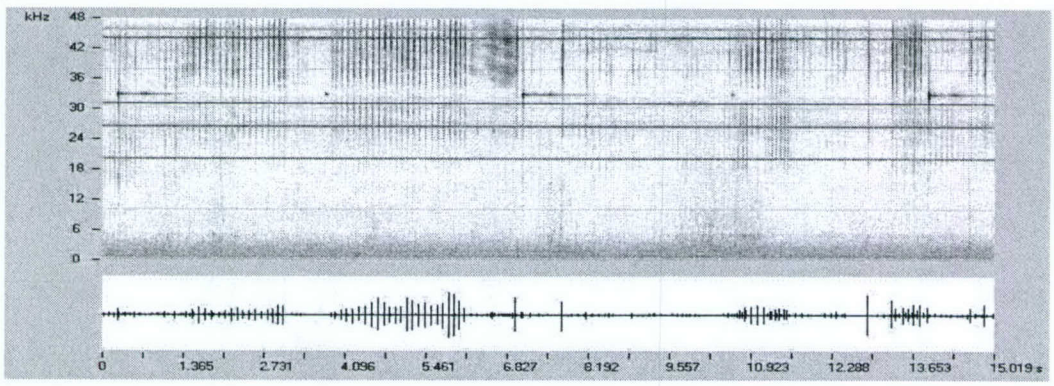

Fig. 4. Spectrogram of dolphin clicks whose energy is above 20 kHz (horizontal lines are due to electrical interferences; traces at 33 kHz are due to the ship's echosounder).

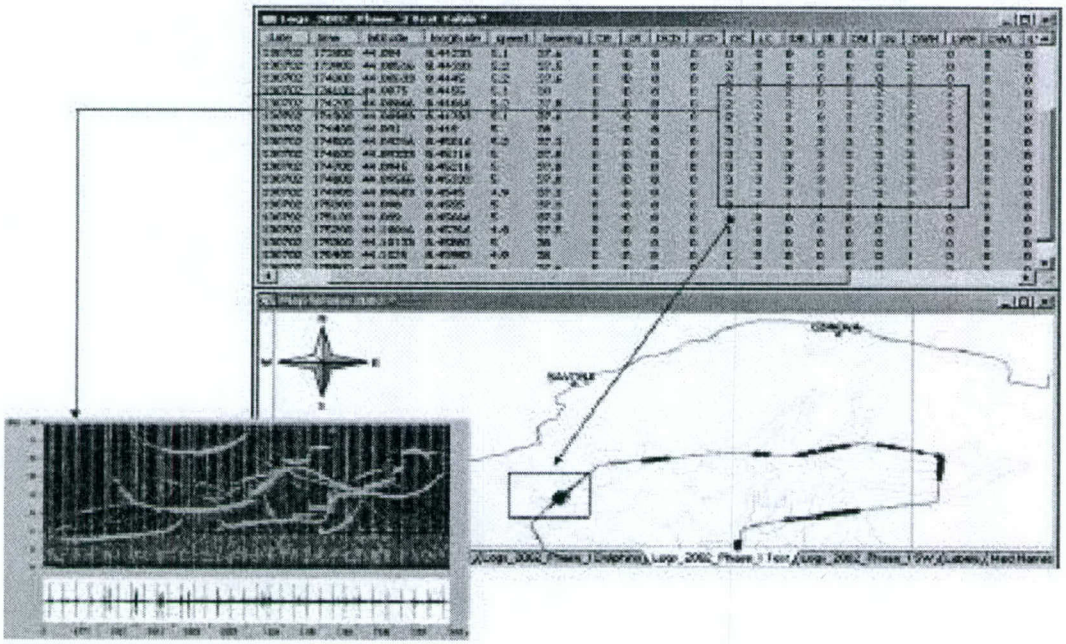

Fig. 5. Acoustic contacts can be plotted on a GIS in real-time to give a complete picture of the acoustic activity in an area. Furthermore, the acoustic logging with 1 minute time resolution becomes an index to recordings for making easy and quick the post-processing of the data.

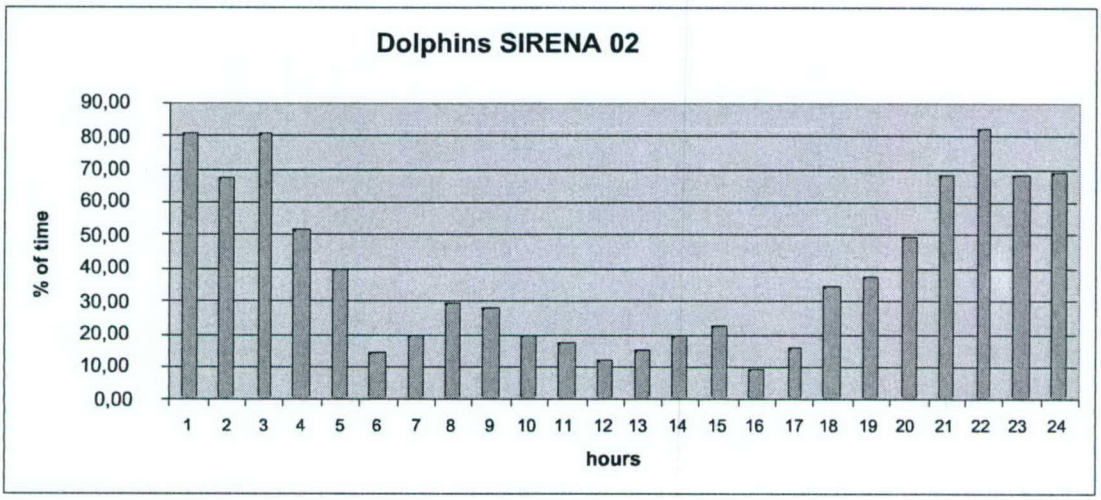

Fig. 6. Detection rates of dolphin vocalisations *vs* time of day. The white bar shows the sunrise-sunset interval. Detection rates (Y axis) are computed as % of minutes with positive detections in each hour.

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Acoustic detection of UHE neutrinos: a station for measurement of the deep sea acoustic noise

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For the NEMO Collaboration

Abstract

The INFN NEMO (NEutrino Mediterranean Observatory) collaboration, aims at the construction of a km^3 underwater Cherenkov neutrino telescope. In this framework NEMO is installing a *Test Site* facility at 2000 m depth, at ~25 km offshore the port of Catania (Sicily), that will be used to test a prototype module of the future km^3 detector. The collaboration is also studying the possibility to use the thermo-acoustic technique to detect UHE neutrino fluxes. One of the major sources of uncertainty in the reliability of this technique is, presently, the lack of knowledge of the acoustic noise at large depth. For this reason NEMO has developed a station for the measurement of acoustic background, that will be installed at the *Test Site*. The station is equipped with four large bandwidth hydrophones (1 Hz–50 kHz) whose data, digitized underwater, will be transmitted to shore through optical fibres. The station will also be used, in collaboration with CIBRA, for research on marine mammals.

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Keywords: Acoustic neutrino detection; NEMO; Neutrino telescope; Underwater noise

1. Acoustic detection of UHE neutrinos

The scientific interest in neutrino astronomy is leading to the construction of two km^3-scale Cherenkov neutrino telescopes, one located in the South Pole (ICECUBE [1]) and another one located in the Mediterranean Sea (ANTARES-NEMO-NESTOR [2]). These detectors are arrays of large area photomultipliers (typically 8-15 in. diameter) designed to detect Cherenkov light irradiated by charged leptons generated in neutrino interactions. The reconstruction of Cherenkov tracks allows the identification of the neutrino direction and energy. The AMANDA and BAIKAL detectors have already demonstrated the possibility to use this technique to track TeV neutrinos [5]. On the other hand, in seawater and ice, light is absorbed in relatively short distances (about 100 m). This implies that presently affordable detectors, equipped with ~5000 PMTs, may reach detection areas of few km^2. At $E_\nu \geqslant 10$ PeV, where the expected neutrino fluxes are fainter, a different detection technique was suggested [3]. At these energies neutrino interactions in water

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produce showers, which release instantaneously a macroscopic amount of energy in a small volume of matter. Ionization and sudden heating of water produce a bipolar pressure pulse which expands perpendicularly to the shower axis. The maximum wave amplitude, calculated with thermo-acoustic models, scales linearly with the density of energy deposition: for a 10 PeV e.m. shower it is ~ 10 μPa at a distance of ~ 1 km from the shower core [4–6]. The wave peak frequency is estimated to be in the range of 10 kHz. The acoustic technique could be extremely fruitful because the sound absorption length is, in this frequency range, of the order of km. A pioneering work in this field has been recently conducted using military arrays of hydrophones [7].

The knowledge of acoustic background is fundamental in order to carry out a feasibility study for an underwater acoustic neutrino detector. Noise in the sea is mainly produced by three different sources: wind and surface waves, navigation and molecular thermal vibrations; the former being the most intense in the frequency range of interest. At present, only few measurements of acoustic noise have been carried out at depth larger than 2000 m, where acoustic detectors should be presumably located. At these large depths it is expected that surface noise should be strongly reduced due to the change of sound refraction index with depth. In order to measure the level of acoustic noise in deep Mediterranean Sea, NEMO has developed a station that will be installed at the Catania *Test Site*.

2. NEMO Phase One

During year 2001 the NEMO collaboration has installed a 28 km long electro-optical cable that will permit data transmission from instrumentation moored at 2000 m depth to a shore laboratory, built by INFN-LNS at the port of Catania, Sicily. The facility will be used as a *Test Site* to test new detectors, materials and technical underwater solutions and, finally, to install the NEMO *Phase One*, i.e. a prototypal *module* of the future km^3 neutrino telescope. The present project foresees the installation of two *towers* (semirigid structures of 750 m height and 20 m × 20 m base) holding ~ 100 PMTs, and three *junction boxes* for underwater connections. The collaboration is going to equip the deep sea cable termination with electro-optical connectors suitable for underwater operations with Remotely Operated Vehicles (ROV). At the same time the collaboration will install at the *Test Site* an underwater station for the measurement of acoustic background.

3. The test site acoustic station

The apparatus is composed of four low noise hydrophones TC-4037 manufactured by *RESON*, specially tested for NEMO at 250 bar pressure. TC-4037 are omnidirectional and they have a receiving sensitivity of -173 ± 3 dB and 1 V/μPa (measured using differential preamp +20 dB gain) which is linear over a wide range of frequencies: 1 Hz−50 kHz. The detectors are placed in the vertexes of a tetragonal fiberglass structure (side ~ 1 m). The analog signals are brought, through electric lines galvanically insulated, to two stereo ADCs *Crystal* CS5396, piloted by the same clock. Each CS5396 samples the signals at a rate of 96 kHz with a resolution of 24 bits: the nominal dynamic range of the ADC is 120 dB. The digital outputs of the two ADCs (each one containing the data of two hydrophones, in electric audio protocol SPDIF) are sent to two fiber optic data transmitter manufactured by *Elcomtech*. The data throughput of the transmitter is ~ 14 Mbit/sec, well compatible with the ADC output and the maximum transmitting distance is 80 km ($\lambda = 1550$ nm). The digitization and data transmission electronics is hosted in a pressure resistant glass spherical housing, 17 in. diameter, manufactured by *Nautilus*. The housing is equipped with an electro-optical connector holding two optical contacts (for data transmission to shore) and two electrical contacts (for power supply from shore). In the shore laboratory, data are reconverted into SPDIF protocol by two fiber optic receiver and, then, acquired using PCI audio boards *RME DIGI96-8 PAD* (96 kHz, 24 bit resolution). The station is under test at LNS; the receiving sensitivity is estimated to be ~ 5000 μPa for each channel.

When deployed, the station will permit a constant on-line monitoring of acoustic noise in deep sea in a wide range of frequencies, allowing a detailed modelization of acoustic background at large depth. Despite the achieved resolution, the detection of rare UHE neutrinos interactions is expected to be not affordable. On the side of marine biology applications, the station will be extremely useful to identify and track cetaceans in a range of several tens of km.

References

[1] http://icecube.wisc.edu.
[2] http://nemoweb.lns.infn.it.
[3] G. Askarjan, Atomnaya Energia 3 (1957) 153.
[4] J.G. Learned, Phys. Rev. D 19 (1979) 3293.
[5] C. Spiering, J. Phys. G 29 (2003) 843 and references therein.
[6] A. Capone, et al., Proceedings of 27th ICRC, 2001, p. 1264.
[7] N.G. Lehtinen, et al., Astropart Phys. 17 (2002) 279.

Atti Soc. it. Sci. nat. Museo civ. Stor. nat. Milano, 144 (I): 75-81, Giugno 2003

Claudio Fossati, Michele Manghi, Gianni Pavan & Marco Priano

Stima acustica della crescita di un capodoglio (*Physeter macrocephalus* Linnaeus, 1758) ricatturato in Mar Ligure

Riassunto – Nel giugno 1995, al largo di La Spezia (Mar Ligure), fu avvistato, fotoidentificato e seguito acusticamente un capodoglio *Physeter macrocephalus*, e furono registrate le sue vocalizzazioni. Circa 15 mesi più tardi, nel settembre del 1996, l'animale fu "ricatturato", riconosciuto tramite la comparazione del profilo della coda e nuovamente registrato acusticamente al largo di Calvi (Corsica). Applicando un particolare metodo di analisi ai segnali acustici registrati durante i due successivi avvistamenti, si sono potute determinare le dimensioni del capo dell'animale e, quindi, le sue dimensioni complessive. L'animale risultò cresciuto di circa 30 cm nel periodo intercorrente la cattura e la ricattura. Questo metodo, per la prima volta applicato in Mar Mediterraneo, costituisce una valida opportunità per approfondire gli studi di dinamiche individuali e di popolazione dei capodogli del Mediterraneo.

Parole chiave: Mar Ligure, capodoglio, analisi acustica, fotoidentificazione, IPI.

Abstract – Acoustic assessment of a recaptured sperm whale's (*Physeter macrocephalus* Linnaeus, 1758) body growth in the Ligurian Sea (Italy).

In June 1995, in the Ligurian Sea off La Spezia, an isolated sperm whale *Physeter macrocephalus* L., 1758 was acoustically detected, recorded, tracked and sighted. Pictures of its fluke were taken. About 15 months later, September 1996, off Calvi (Corse, FR), the same animal was sighted again and recognized thanks to the comparison of the natural markings on its fluke. Audio recordings were collected as well. Through the application of the acoustic method to the two recordings dataset, it was possible to determine the length of the animal. During the 15 months lapse, its dimension augmented of about 30 centimetres. The acoustic method, never applied in the Mediterranean Sea before the event described, proves to be a valid opportunity to investigate the individual and population dynamics among sperm whales of the Mediterranean Sea.

Key-words: Ligurian Sea, sperm whale, acoustic analysis, photo identification, IPI.

Introduzione

Dal 1989, il Centro Interdisciplinare di Bioacustica e Ricerche Ambientali dell'Università di Pavia conduce crociere di ricerca nel Mediterraneo con lo scopo di studiare il comportamento acustico dei cetacei e le loro relazioni con l'ambiente circostante. Durante queste crociere è stato più volte possibile fotoidentificare i

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capodogli rilevati e seguiti acusticamente mediante l'uso di idrofoni trainati (Pavan & Borsani, 1997; Priano *et al.*, 2001).

Secondo Arnborm (1987), il capodoglio (*Physeter macrocephalus* L., 1758) può essere identificato individualmente grazie ai *natural markings* presenti sul profilo della pinna caudale.

Organizzando in un catalogo le fotografie delle code scattate al momento dell'immersione, è possibile verificare eventuali ricatture utilizzando la permanenza dei *natural markings* peculiari di ciascun individuo (Hammond, 1986; Whitehead, 1990; Whitehead *et al.* 1992).

Negli anni successivi all'esperimento descritto in questo lavoro, numerosi gruppi di ricerca hanno contribuito alla costituzione di un catalogo comune per la raccolta e la condivisione delle fotografie identificative di capodogli del Mar Mediterraneo e dell'Atlantico settentrionale – NAMSC – North Atlantic & Mediterranean Sperm Whale Catalogue (Huele *et al.*, 2000), successivamente confluito nel progetto Europhlukes.

Materiali e Metodi

Dal 1991 al 1997 il Centro di Bioacustica ha organizzato e svolto diverse crociere di ricerca espressamente dedicate allo studio dell'acustica del capodoglio, totalizzando 110 giorni in mare, 3.400 miglia nautiche percorse e 580 ore di monitoraggio acustico (Priano *et al.*, 2001). Le registrazioni di repertorio acustico di capodoglio effettuate in tale periodo, conservate e classificate nella nostra fonoteca, ammontano a più di 100 ore. La ricerca in mare, condotta su *motorsailer* di 12-14 m, si è avvalsa di un idrofono trainato caratterizzato da basso rumore ed elevata larghezza di banda (> 40 kHz), collegato a un registratore DAT (larghezza di banda 22 kHz) (Pavan & Borsani, 1997) e a un PC per la visualizzazione degli spettrogrammi audio; tale strumentazione rende possibile l'ascolto continuo durante la navigazione, la registrazione dei segnali acustici e il *tracking* delle sorgenti.

Le rotte indicative delle crociere del 1995 e 1996, oggetto di questo studio, sono riportate nella tabella 1.

Tab. 1 - Dati generali crociere 1995 e 1996.
Tab. 1 - Data overview of 1995 and 1996 cruises.

	Crociera giugno 1995	**Crociera settembre 1996**
Imbarcazione	Motorsaliler Carolin 13.50 m	Motorsailer Aleph 16 m
Rotta indicativa	La Spezia-S. Remo - S. Florent-La Spezia	S. Remo-Calvi - S. Remo
Miglia percorse	340 nm	435 nm
Registrazioni capodoglio	7h20min	27h

Tab. 2 - Dettagli del tracking acustico e degli avvistamenti.
Tab. 2 - Acoustic tracking and sightings details.

ID individuo	**Lat**	**Long**	**Ac. tracking**	**N° avvist.**	**Luogo**
SW0695	43°46'N	09°20'E	8h25min	8	Largo di La Spezia
SW0996a	42°43'N	08°52'E	4h20min	3	Calvi, Corsica (FR)

Per i capodogli è possibile stimare le dimensioni anche tramite l'applicazione di un metodo acustico (Clarke, 1978; Gordon, 1991; Goold, 1996; Pavan *et al.*, 1997) basato sulla misura dell'IPI, *Inter Pulse Interval* (Norris & Harvey, 1972) di ciascun *click*. Questo tipo di analisi permette infatti di distinguere, all'interno di ciascun *click*, almeno due impulsi successivi (Fig. 1). Il primo, definito "impulso diretto", proviene dall'organo di produzione del suono, situato anteriormente allo spermaceti dell'animale. Il secondo, al contrario, arriva all'idrofono dopo una riflessione in senso longitudinale interna allo spermaceti. La misura del ritardo fra i due impulsi, tradotta in distanza, corrisponde al doppio della lunghezza dello spermaceti. Clarke (1978) e Gordon (1991) hanno elaborato ciascuno un'equazione che, applicata alla misura del ritardo, e quindi alla dimensione dello spermaceti, permette di risalire alle dimensioni totali dell'animale.

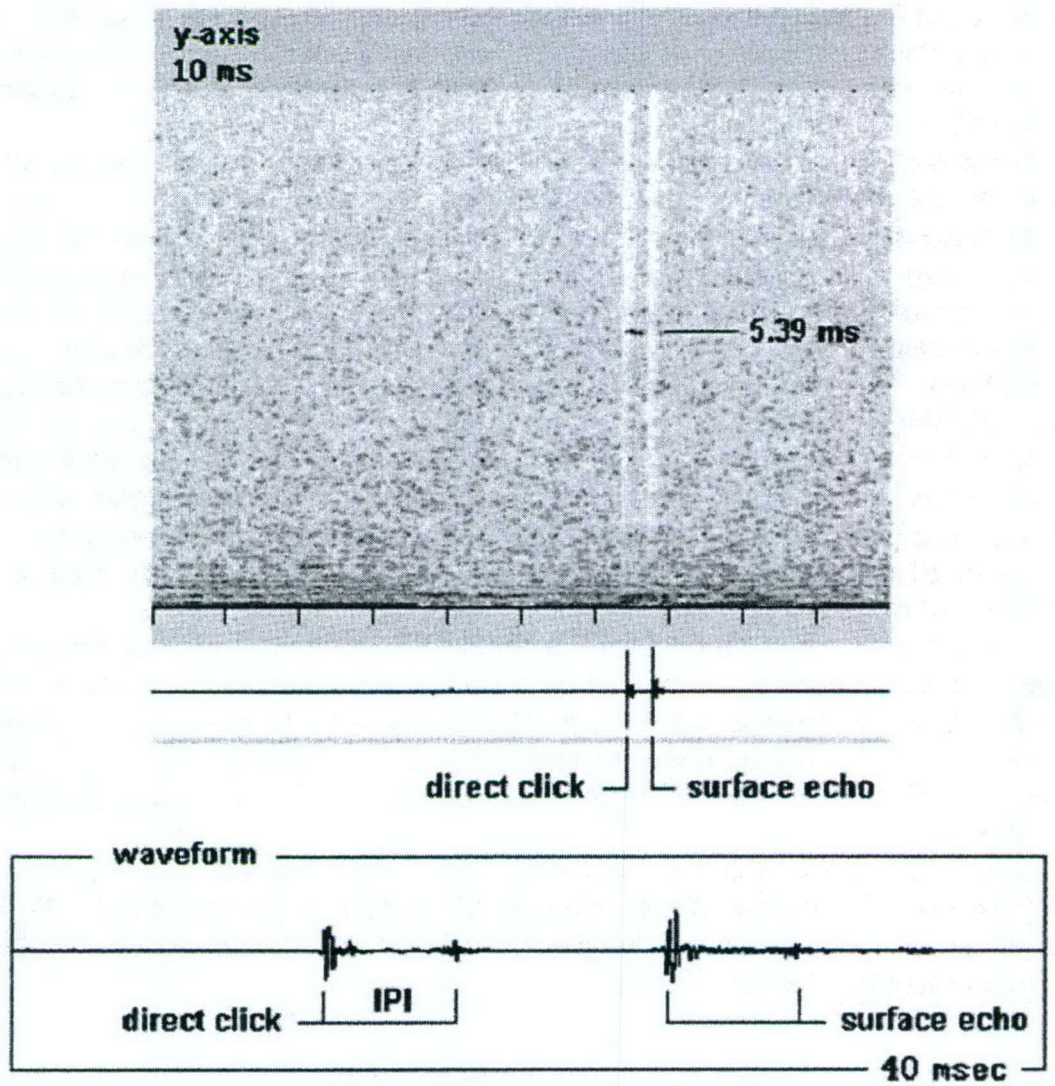

Fig. 1 - Visualizzazione (spettrogramma e forma d'onda) dell'IPI relativo a un *click* di SW0996. Notare la stabilità del ritardo (5,39 ms) sia nel *click* principale (*direct click* in figura) che nel suo eco sulla superficie del mare (*surface echo*).
Fig. 1 - Spectrogram and waveform of one IPI extracted from a SW0996 *click*. Notice the delay stability (5.39 ms) in both the direct *click* and its echo from the sea surface.

Una funzione del software sviluppato internamente al Centro di Bioacustica, rende agevole e affidabile la misura dell'IPI visualizzandola graficamente in tempo reale (Pavan et *al.*, 1997). Il metodo, applicato in tempo reale alle registrazioni effettuate in mare, consentì di discriminare i vari capodogli presenti e di seguire acusticamente il solo capodoglio identificato. La successiva analisi delle registrazioni ha consentito di misurare accuratamente il valore dell'IPI su un ampio campione e di evidenziare la bassa variabilità dello stesso anche durante immersioni consecutive.

Risultati

Nel giugno 1995, durante una crociera di ricerca in Mar Ligure, un capodoglio, denominato SW0695 (Tab. 2) fu acusticamente individuato e seguito per più di otto ore al largo di La Spezia. Fu avvistato in superficie per otto volte consecutive e le fotografie ottenute permisero la sua identificazione. Il materiale fotografico ottenuto fu incluso nel catalogo di capodogli fotoidentificati del Centro di Bioacustica e Ricerche Ambientali dell'Università di Pavia (Priano *et al.* 1997) e nel catalogo NAMSC.

Il *tracking* (inseguimento) acustico permise di ottenere diverse ore di registrazione di alta qualità delle sue vocalizzazioni.

Durante una crociera di ricerca nel settembre 1996, sette capodogli furono rilevati al largo di Calvi (Corsica, FR). Tre di questi furono fotoidentificati. Degli stessi animali furono raccolte diverse ore di registrazioni acustiche. Fra i tre animali fotoidentificati, la comparazione dei *natural markings* delle code (Dufault and Whitehead, 1995) permise di riconoscere l'animale SW0695, nell'occasione nominato SW0996A (Fig. 2).

Grazie alla visualizzazione della misura dell'IPI rilevata sui click emessi subito dopo le immersioni fotoidentificate (Pavan *et al.*, 2000), questo individuo fu seguito e registrato separatamente dagli altri per più di quattro ore (Tab. 2). In entrambi gli avvistamenti, le dimensioni dell'animale, stimate a vista, furono valutate fra i 12 e i 13 m.

Dalle registrazioni raccolte dall'animale SW0695 su 8 cicli di immersione consecutivi, fu possibile estrarre un valore medio dell'IPI calcolato da 756 *click* pari a 5,17 millisecondi (Tab. 3) che, secondo l'equazione proposta da Clarke (1978), corrispondono ad una lunghezza totale del corpo di 11,65 m, mentre applicando la formula proposta da Gordon (1991) il valore risulta essere di 12,33 m.

Nelle registrazioni effettuate nel 1996, su 3 immersioni successive dello stesso animale, la durata media dell'IPI rilevata dall'analisi di 334 *click* fu di 5,39 millisecondi, corrispondente a una lunghezza di 11,99 m secondo Clarke (1978) e di 12,62 m secondo Gordon (1991).

Tab. 3 - Click analizzati e statistica.
Tab. 3 - Analysed clicks.

Individui	N	Somma	Media	Varianza
SW0695	756	3909.6299	5.1714	0.0046
SW0996A	334	1800.0733	5.3894	0.0017

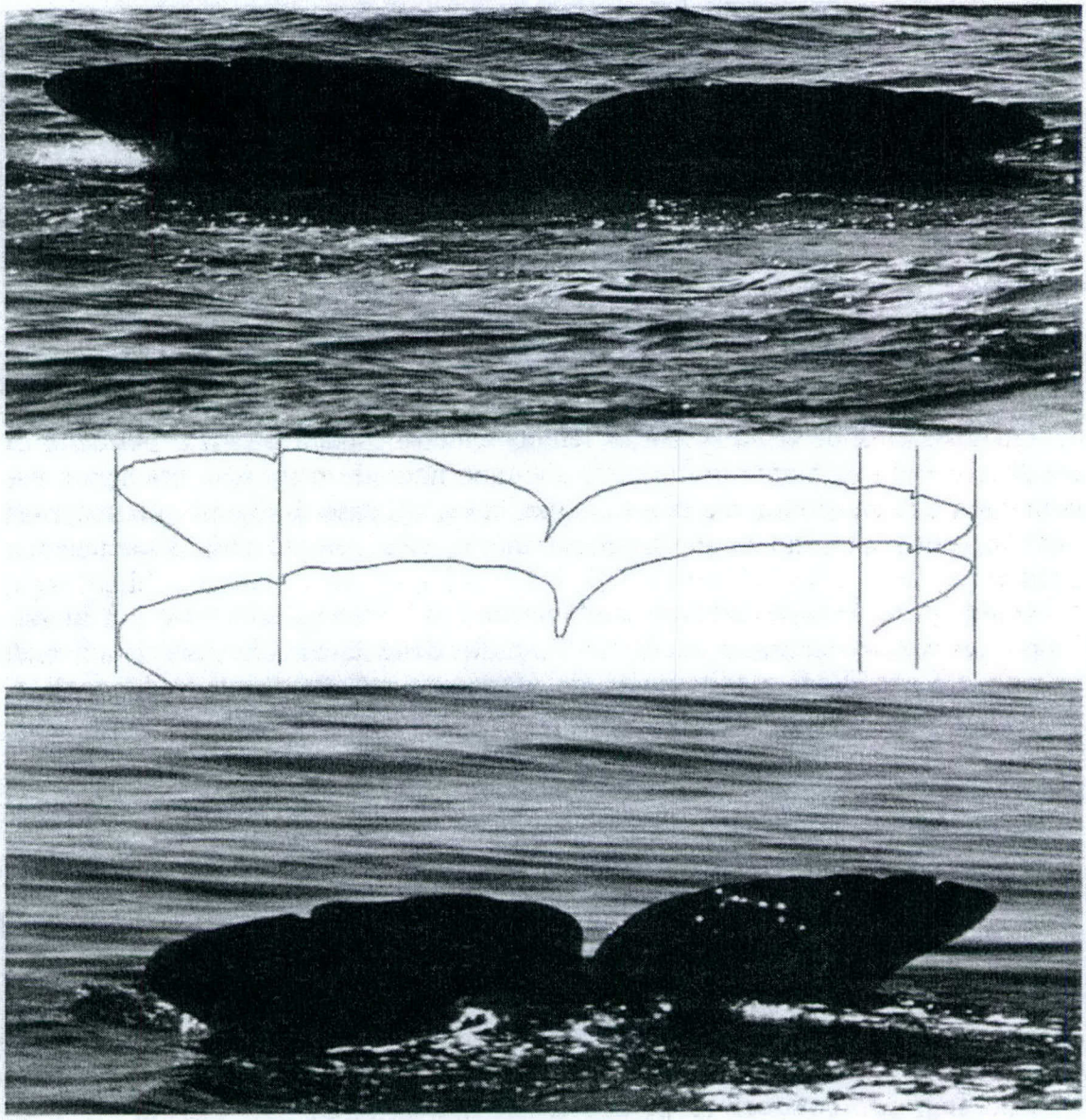

Fig. 2 - Comparazione dei profili delle code risultanti dalle foto ID del giugno 1995 (in alto) e del settembre 1996 (in basso).
Fig. 2 - Comparison of the tales' edge from the photo-id taken in 1995 (upper picture) and 1996 (lower picture).

La differenza tra la media degli IPI dei due campioni (SW0695 e SW0996A) è statisticamente significativa ($F_{1,1088} = 2939{,}387$, $P < 0{,}01$) (Tab. 4).

Tab. 4 - Test ANOVA.
Tab. 4 - ANOVA test.

Fonte di variazione	Devianza	Gradi di libertà	Varianza	F	Valore di P	F critico
Tra gruppi	11.00643	1	11.00643	2939.387	<0.01	6.658183
Entro gruppi	4.073976	1088	0.003744			
Totale	15.0804	1089				

L'incremento delle dimensioni nel periodo di tempo intercorso fu quindi di 34 e 29 cm rispettivamente, secondo la formula applicata.

La lunghezza totale del corpo ottenuta in entrambe le rilevazioni corrisponde a un individuo maschio di 9 – 10 anni di età (Berzin, 1971). L'interessante dato sul valore di crescita ottenuto mediante il metodo acustico rientra negli intervalli di crescita descritti da Berzin per capodogli maschi di quell'età.

Discussione

L'applicazione di questo metodo è strettamente legata alla stabilità dell'IPI rilevato, a sua volta dipendente da una serie di fattori, alcuni dei quali ancora poco noti. In particolare, la qualità della strumentazione di rilevamento e analisi, il rapporto fra segnale e rumore ambiente e la corretta profondità dell'idrofono sono condizioni essenziali per l'ottenimento di misure IPI affidabili.

La possibilità di visualizzare in tempo reale la misura dell'IPI, permette di seguire il comportamento individuale anche di animali in gruppo, ottenendo nel contempo informazioni circa la loro taglia, età e, nel caso di dimensioni superiori ai 12 m, anche sul sesso. In questa specie, infatti, solo i maschi adulti superano tale valore.

Questi primi risultati ottenuti costituiscono un'incoraggiante base per lo sviluppo del metodo acustico anche nello studio delle dinamiche individuali e di gruppo dei capodogli mediterranei, da affiancare agli strumenti tradizionali di fotoidentificazione.

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Bibliografia

Arnborm T., 1987 - Individual identification of sperm whale. *Rep. Int. Whal. Comm.*, 37: 201-204.

Berzin A., 1971 - The sperm whale. Translated from Russian. *Israel program for scientific translations*, Jerusalem, 1972.

Clarke M.R., 1978 - Structure and proportions of the spermaceti organ in the sperm whale. *J. Mar. Biol. Ass. U.K.*, 58: 1-17.

Dufault S. & Whitehead A., 1995 - An assessment of changes with time in the marking pattern used for photoidentification of individual sperm whales, *Physeter macrocephalus*. *Marine Mammal Science*, 11 (3): 335-343.

Goold J. C., 1996 - Signal processing techniques for acoustic measurement of sperm whale body lengths. *J. Acoust. Soc. Am.*, 100 (5): 3431-3441.

Gordon J. C. D., 1991 - Evaluation of a method for determining the length of sperm whales (*Physeter catodon*) from their vocalizations. *J. Zool.*, London, 224: 310-314.

Hammond P. S., 1986 - Estimating the size of naturally marked whale populations using capture-recapture techniques. *Rep. Int. Whal. Comm.* (Special Issue 8): 253-282.

Huele R., Udo de Haes H. A., Ciano J. N. & Gordon J., 2000 - Finding similar trailing edges in large collections of photographs of sperm whales. *J. Cetacean Res. Manage*, 2 (3): 173-176.

Norris K. S. & Harvey G., 1972 - A theory of the function of the spermaceti organ of the sperm whale *Physeter catodon.* In: Animal Orientation and Navigation. Galler S. R., Schmidt Koenig K., Jacobs G. J. & Belleville R. E. (eds.). *NASA Spec. Publ.*, 262: 397-417.

Pavan G., Priano M., Manghi M. & Fossati C., 1997 - Software tools for real time IPI measurements on sperm whale sounds. Underwater Bio-Sonar and Bioacoustic Symposium. *Proc. I.O.A.*, Loughborough, UK, 19 (9): 157-164.

Pavan G. & Borsani F., 1997 - Bioacoustics research on cetaceans in the Mediterranean sea. *Mar. Fresh. Behav. Physiol.*, 30: 99-123.

Pavan G., Hayward T. J., Borsani F., Priano M., Manghi M., Fossati C. & Gordon J., 2000 - Time patterns of sperm whales codas recorded in the Mediterranean Sea 1985 -1996. *J. Acoust. Soc. Am.* 107 (6): 3487 – 3495.

Priano M., Pavan G., Manghi M. & Fossati C., 1997 - The Cetacean Sound Library of the Interdisciplinary Center for Bioacoustics and Environmental Research of the University of Pavia. Proc. Underwater Bio-Sonar and Bioacoustic Symposium. *Proc. I.O.A.*, Loughborough, UK, 19 (9): 245-249.

Priano M., Pavan G., Manghi M. & Fossati C., 2001 - Rilievi acustici sul capodoglio (*Physeter macrocephalus*) nel Mar Mediterraneo Centrale. *Natura,* Milano, 90 (2): 181-188.

Whitehead H., 1990 - Mark-recapture estimates with emigration and reimmigration. *Biometrics*, 46: 473-479.

Whitehead H., Waters S. & Lyrholm T., 1992 - Population structure of female and immature sperm whales (*Physeter macrocephalus*) off the Galapagos Islands. *Can. J. Fish. Aquat. Sci.*, 49: 78-84.

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