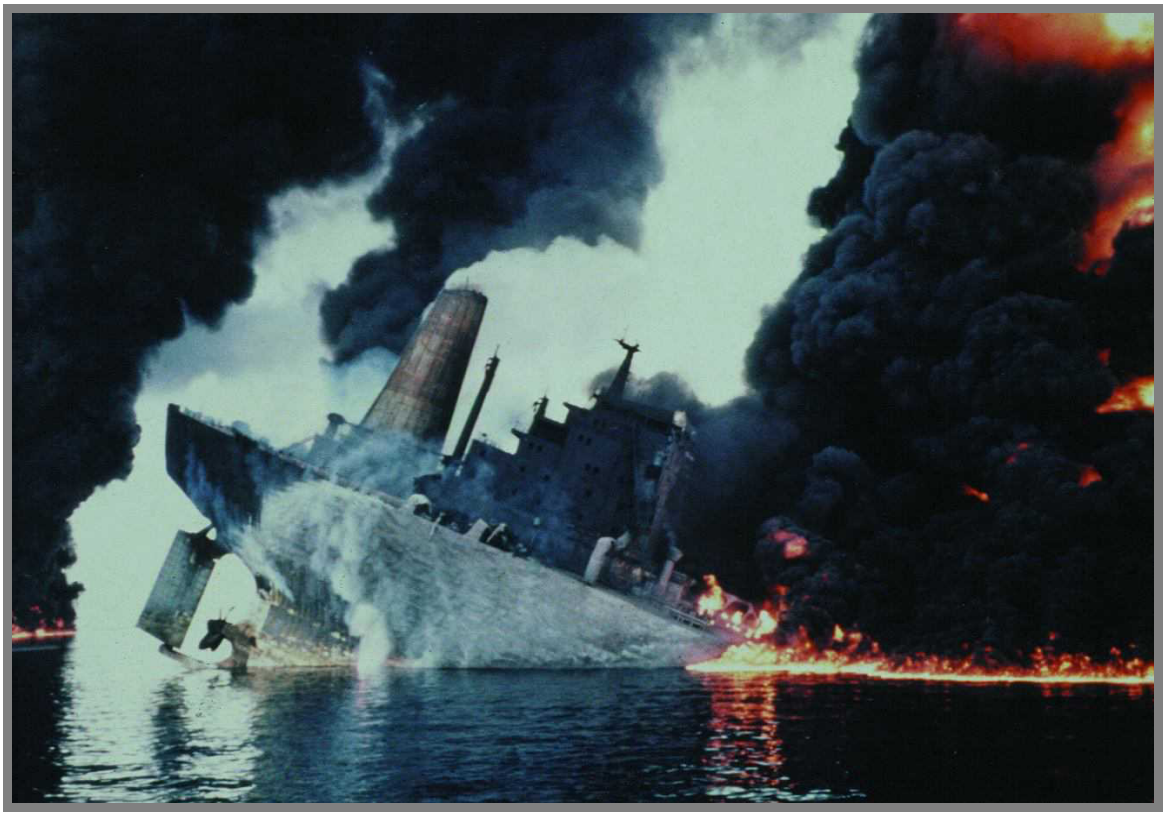
An Environmental Restoration Programme 12 Years After: the HAVEN Wreck

E. Amato
ICRAM–Central institute for marine applied research
Via di Casalotti 300, 00166 Rome, Italy

e.amato@icram.org



Synopsis

The VLCC "HAVEN" accident is the major case of oil spill ever occurred in the Mediterranean Sea. On April 11th 1991, while the "HAVEN" was anchored in front of the port of Genoa, two violent explosions started a fire within the ship that was extinguished only 70 hours later when the Very Large Crude Carrier sunk. At the moment of the accident the ship was carrying 144.000 tons of "heavy Iranian crude oil". A large quantity of burnt oil rapidly sank in form of bitumen, while the rest of the cargo was dispersed by the Ligurian-Provençal current and by the winds.

During the emergency phase operations began in order to contain the pollution. Two important decisions were taken: to tug the ship coastward and to allow the burning of the greatest part of the oil spilled at sea.
The operations concerned the containment of the spilled oil, the collection of the oil both at sea and on shore and the performing of an environmental control and monitoring plan.
Twelve years later a restoration programme is on the way mainly dealing with the tar residues laying on the seabed and with the oil products still contained in the wreck. In this framework, in order to assess quantities and locations of the oil residues a contract has just been signed with a consortium. The work to be carried out is an example of how difficult it could be to deal with the cleaning up of a VLCC wreck. Divers have to explore the wreck and characterize and quantify the oil residues facing poor visibility, considerable depths, hardly accessible storage tanks and time and economical resources constraints. Also the administrative procedures carried out by the appointed committee in order to assign the task have shown to be complicated by the need to cope the legal framework with the peculiarities of the case.

Introduction

The VLCC "HAVEN" accident is the major case of oil spill ever occurred in the Mediterranean Sea and one of the worst in the world related to maritime oil transport. On April 11th 1991 at 12.30 a.m., only twelve hours after the collision between the M/C "AGIP ABRUZZO" and the ferry "MOBY PRINCE" in front of Livorno, the Cypriot VLCC "HAVEN" was at anchor in front of the port of Genoa when two violent explosions (the causes are still unknown) started a fire that was extinguished 70 hours later, on April 14th at 10.15 a.m., when the ship sunk.

Table I. VLCC HAVEN main characteristics

Name	HAVEN (ex AMOCO MILFORD HAVEN) Limassol (Cyprus)
Shipyard	Astilleros Españoles S.A., Cadiz (Spain), 1973
Class	A1 Oil Carrier, American Bureau of Shipping
Overall length	334.02 m
Beam	51.06 m
Upper deck height	26.18 m

Draught	19.91 m
Gross Tonnage	109,700 Ton
Net Tonnage	91,988 Ton
Dead weight	35,395 Ton
Main engine	(8k98 FF) diesel, two-stoke, 8 cylinders in line (bore 980 mm, stroke 2,000 mm), 30.400 BHP (103 RPM)
Speed under full load (28.000 BHP)	15.3 knt
Fuel (ca.)	9000 t
Tanks	13 tanks (3 central, 5 to starboard, 5 to port), total volume 283,626 m^3 Tank No. 2 central: segregated ballast
Capacity (d. w.)	232,164 Ton
Equipment	Inert Gas System, Crude Oil Washing, Segregated Ballast Tanks

At the moment of the accident, which killed five members of the crew, 144,000 tons of "heavy Iranian crude oil" and 1,223 tons (appraisal) of fuel oil and diesel were present on board.

Table II. Main properties of the crude oil

Type	Category	Specific gravity	Viscosity (cSt)	Pour point (°C)
Iranian heavy	Average paraffin content	0.869	30 @10°C	-7

A large quantity of burnt oil rapidly sank in the form of bitumen while the rest of the cargo was dispersed by the Ligurian-Provençal current and the winds mainly west-south-westerly; according to the satellite images elaboration carried out by a team of experts, a few hours after the sinking of the HAVEN, the oil slicks had affected nearly 100 km^2 of the sea surface. According to REMPEC (REMPEC, 1991)[1] until April 25th the wreck released oil continuously at a rate of ten cubic metres per hour during the first two days and about one cubic metre per day by the end of the second week after the accident. The 70 hour burning determined the sinking, in a restricted area of the sea bottom, of an amount of oil estimated in the range 10,000÷50,000 tons (Medugno, 1992; Fresi, 1992; Volterra, 1992)[2, 3, 4].

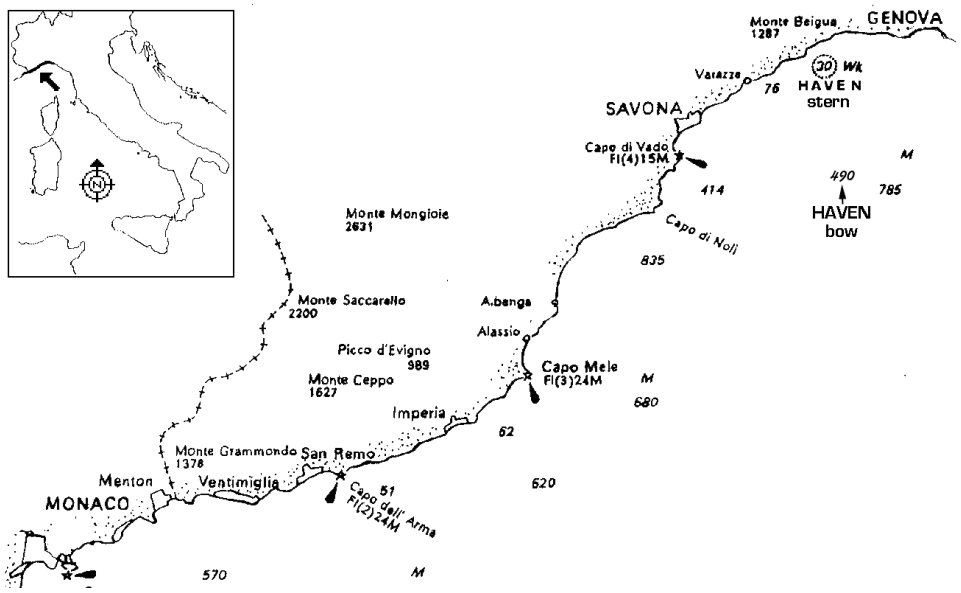


Figure 1. The Ligurian coast affected by the oil spill. The position of the VLCC "HAVEN" is shown.

Due to the first explosion, the ship lost the deck of the central tank No 1 and part of the central tank No 2 and during the towage of the burning wreck coastward, it broke into two parts. The bow part with two tanks lies at 490 m depth, while the main part (220 m of length) is situated at 75-78 meters depth 1.5 nm offshore Arenzano (Fig. 1).

Figure 2. The VLCC "HAVEN" burning in front of Arenzano.

Oil products released in the marine environment

Once spilled at sea, the oil products were exposed to a series of physical and chemical processes that determined their fate at sea. Some of the spilled oil was collected directly from the sea surface (A.T.I. ENI-IRI,1991a)[5], some was washed ashore (A.T.I. ENI-IRI 1991b)[6], another part spread out from the intervention area, and the remaining part sunk. The total amount of petroleum hydrocarbons that burned during the 70 hours following the first explosion was estimated in the range 95,500÷103,500 tons while 3,000 tons have been appraised as still trapped inside the wreck, mainly in solid form. The values shown in the table below have been estimated taking into account the meteo-marine conditions at the moment of the accident and during the following days and the physical-chemical processes that took place during each phase of the accident.

Table III. Oil products released at sea (Aquater S.p.A., Bonifica S.p.A., 1993, modified)[7]

Evaporated	14,500÷17,000 t
Burnt	95,500÷103,500 t
Washed ashore	1,000÷1,500 t
Collected from the sea surface	2,000 t
Sunk	10,000÷50,000 t
In the wreck	3,000 t
Dispersed at sea	3,500÷5,000 t

The emergency phase

During the emergency phase, operations began in order to contain pollution. Many difficulties were encountered as most of the intervention teams were already involved in responding to the other accident occurred near Leghorn twelve hours earlier. This phase of local emergency started at the moment of the accident and lasted until April 14th when the national emergency was declared.

In both phases, all the operations were co-ordinated by the commander of the *Capitaneria di Porto* (coast guard) of Genoa Adm. A. Alati; when the national emergency was declared the National Emergency Committee appointed him as on-scene commander. Furthermore, a "crisis unit" was established at the Ministry of the Environment in order to take care, specifically, of the environmental aspects.

While the "HAVEN" was burning, two important decisions were taken:

- to tug the wreck coastward, in order to prevent it from eventually sinking at depths where it would be extremely difficult to take any action and to contain pollution on the coast;
- to allow the burning of the greatest part of the oil spilled at sea (the fire was kept in a circumscribed area by means of water-jets) to contain the spreading of the product on the sea surface and pollution on the coast.

The operations concerned:

- The containment of the spilled products through the use of booms;
- The collection of the spilled products at sea by means of disc-oil skimmers;
- The collection of the spilled products on shore;
- The protection of harbours and of the coast from the black tide.

Dispersants were not utilised at all.

A series of parameters were monitored and data were collected in the framework of a control and monitoring plan utilising vessels, satellites and planes. During the two weeks following the accident, the anti-pollution vessels were operated along 8,000 hours, 11,000 tons of emulsion were collected at sea and almost 20,000 meters of booms were employed.

Fortunately, the good weather conditions, which characterised the days following the accident, permitted the operators to work properly and to contain environmental damage.

Safety measures

During the days following the accident a plan was elaborated in order to start the operations as soon as the emergency phase had ended (May the 22nd). The plan was divided into the following projects (Persiani, 1992)[8]:

- Measures to safeguard the main part of the wreck. The wreck has been inspected and the liquid hydrocarbons leaking from it were collected by means of suction skimmers (this operation has been repeated three times until 1995, but the phenomenon has never been extinguished). The parts of the wreck that obstructed navigation were removed.
- Investigation of the sea bottom near the "main" wreck by means of Side Scan Sonar, Sub Bottom Profiler and Remotely Operated Vehicle. The results indicated that the sea bottom within 1,000-1,200 meters from the wreck was affected by tar depositions 10 cm thick, covering an area of 120,000 m^2.
- Monitoring of air, sea water, sediments, beaches, rocky coasts, marine fauna and flora. A data base was set up for the information already available and for the information gathered by the control and monitoring plan.

- Clean-up operations at sea. Oil residuals that were sunk within 10 meters depth were localised and removed. This operation resulted necessary as the depositions could have turned again into suspension and cause further pollution on land. Since there were no previous experiences for reclaiming such broad areas of the sea floor, several operative techniques were developed and tested to guarantee respect for the morphology of the sea floor and underwater flora and fauna. Manual recovery by divers was the most used method and the one that proved most flexible and successful, since it could be applied to all kinds of sea floor. Manual removal was supplemented by gathering with a specially adapted sort of steel "clam hook". These activities were completed in August 1991 when 200 cubic meters of solid product were collected from the sea floor (Morucci C. *et al*., 2002)[9].
- Clean-up operations on land. The stretches of coast interested by the presence of oil residuals were rather discontinuous. The work on beaches was mechanical with the pollutant oily layer removed with machinery and, in areas that were only slightly polluted, pollutant material was removed manually (tar balls, dirty stones, etc.). Along the rocky coast, breakwater and quays, the action was both mechanical and physical, with environmental temperature sea water cleaners. With this system the crude oil was removed by high pressure water jets, after protecting the working area with appropriate floating barriers. 91 km of sandy beaches, 5.7 km of rocky coast and 7.3 km of breakwater and quays were cleaned. Reclamation covered also 370 vessels anchored in the ports of Arenzano and Varazze. The operations started in May 25th and were substantially completed by the middle of July 1991. An emergency group worked until September 15, 1991 to meet cleaning needs for small re-deposits of hydrocarbon residues along the coast.

Figure 3. A beach contaminated by the oil spill

- Waste disposal. The material recovered offshore (an emulsion of crude oil residue and water) was stored in slop oil tanks. The processing consisted of separating the water from the hydrocarbon residues at Porto Petroli of Genoa Multedo with a suitable mobile plant. The hydrocarbon residues were shipped to a refinery plant for additional processing, including dilution with crude oil, enhanced desalination, separation of pollutants, and finally recovered in the form of oil product.

  The material from reclamation work on the coast and the sea floor was stored in a temporary storehouse located in Voltri and consisted essentially of:

  - stony material (sand, pebbles, gravel, etc.);
  - bituminous residues;
  - other material (including absorbent booms, wreckage, etc.).

  Most of the stony material was utilised as fill for the Voltri port while the other material was disposed in a landfill for special wastes or incinerated.

Environmental monitoring

The Ligurian Sea represents a complex system with diversified trophic chains leading from phytoplankton to Cetaceans. The geographical and oceanographical features of the site, together with the quality and quantity of the spilled product and the evolution of the meteo-marine conditions, are among the variables that may influence the fate of the oil at sea and consequently the effects of the product on the environment. A few weeks after the accident a plan of environmental monitoring was elaborated, although many of its phases were not accomplished following further evaluation and the lack of funds. Besides water and sediment monitoring, which consisted essentially in measuring total hydrocarbon and PAHs content, many analysis were performed on marine fauna. Two hundred samples of mussels collected on the coast near the wreck were analysed. A certain number of "clean" mussels were collected and transferred to the polluted site in order to test the rate of bioaccumulation. Demersal fauna was collected at thirty-six sampling stations (some of them situated where commercial fishing was normally practised) by means of trawlers. This activity, aimed at obtaining data about the status of the commercial stocks, also permitted to find out some tar depositions on the sea floor. At each station all the specimen fished were identified and measured and the amount of oil residues collected was weighed. The results showed that most of the depositions were concentrated between the wreck and Capo Noli (Fig.1, Fig. 4 and Fig. 5).

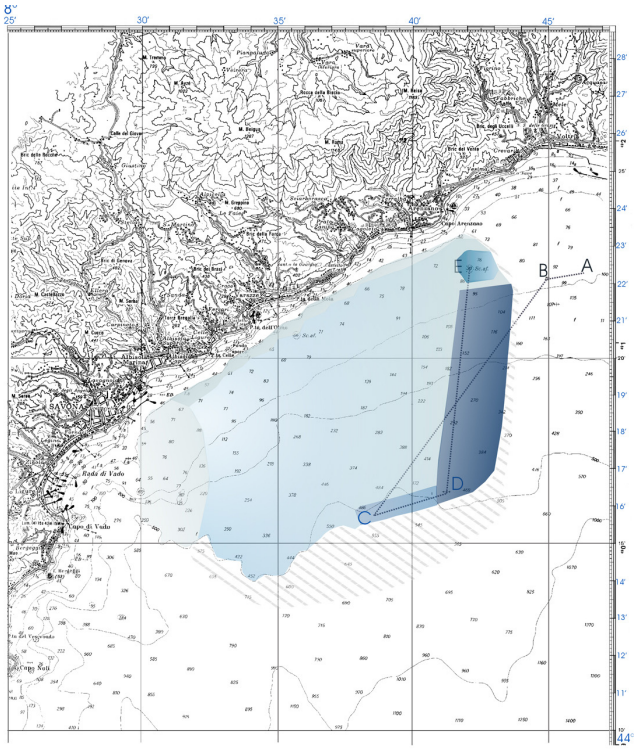


Figure 4. Occurrence of tar deposits on the seabed.

Investigations were performed along the areas where the seagrass *Posidonia oceanica* is situated. A monitoring activity was planned in order to detect any regression of the meadows. Furthermore scientific institutions performed various researches. Some examples are given below.

Between April the 17th and the 22nd a control project was carried out by a team of French and Italian researchers (HAVECO project), aimed at evaluating the short-term effects of the oil spilled at sea (Amato *et al*., 1993)[10]. In order to acquire data about the level and the geographical extent of the environmental contamination produced by the "HAVEN" accident, four cages containing sentinel organisms (specimens of *Dicentrarchus labrax* (Linneus, 1758), *Mytilus galloprovincialis* Lamarck, 1819 and *Crassostrea gigas* (Thunberg, 1793)) were positioned near the seabed at a depth of about 20 and 25 meters. The cages were positioned at increasing distances from the spill site according to a gradient of most probable contamination. Due to the impossibility of recovering all the cages, only the tissues of the organisms contained in one cage, positioned 15 NM from the accident site, were analysed. Although the concentration of aliphatic and polycyclic aromatic hydrocarbons in sediment samples collected next to the cage was comparable to the one already known for the area, the concentration levels of PAHs in the biological matrices showed the existence of a time-related gradient. The oil polluted waters affected the cage site so that the organisms, exposed to the spill effects, testified the event.

Another research, carried out in 1992 by ICRAM, aimed at evaluating the effects of the accident on trawling fisheries. The study area was situated between Arenzano and Savona and was compared with a reference site not directly interested by the HAVEN accident. The results showed that the area of major risk was the one in front of Arenzano, as it was rather common to collect conspicuous tar depositions with the nets (Fig. 4 and Fig. 5). The most evident effects on fishing activities concerned the reduction of the fishing areas and the damage occurred to the nets due to the oil residues. As the fishing areas decreased, it was consequently noted a clear reduction of fish landing. Comparing the results with previous fishing data from the same area, it was registered a 43% of decrease in captures since 1990.

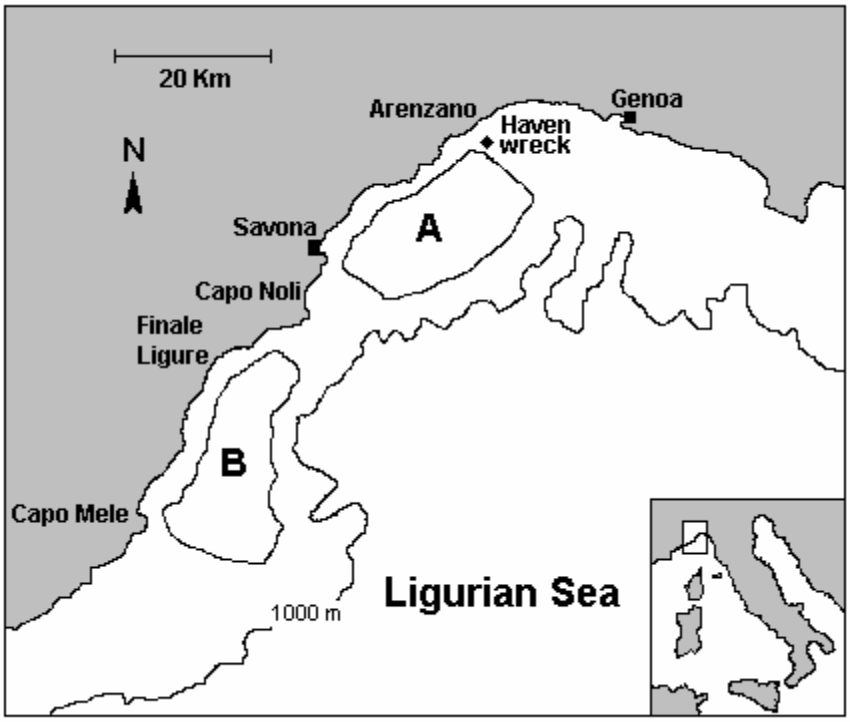


Fig. 5. Main areas of oil residues deposition

In September 1994 three dives by means of the French IFREMER bathyscaph CYANA were carried out, in order to detect the distribution, morphology and characteristics of some deep tar depositions and to observe *de visu* the benthic fauna associated (Amato E. *et al*., 2002)[11]. The sea bottom at about 350 meters depth was characterised by various depositions, rather consistent, on which benthic organisms (*Hydroida*, *Polychaeta, Serpulidae*, *Eledone sp*., *Munida sp*., *Antedon sp*., etc.) and bento-nektonic fish were associated. According to the measured levels of PAHs found in sediment cores (Table IV) collected by means of the bathyscaph near some tar deposit (Fig. 6), the depositions are likely to determine the contamination of the trophic nets and to contribute to the alteration of the ecosystem *equilibria*.

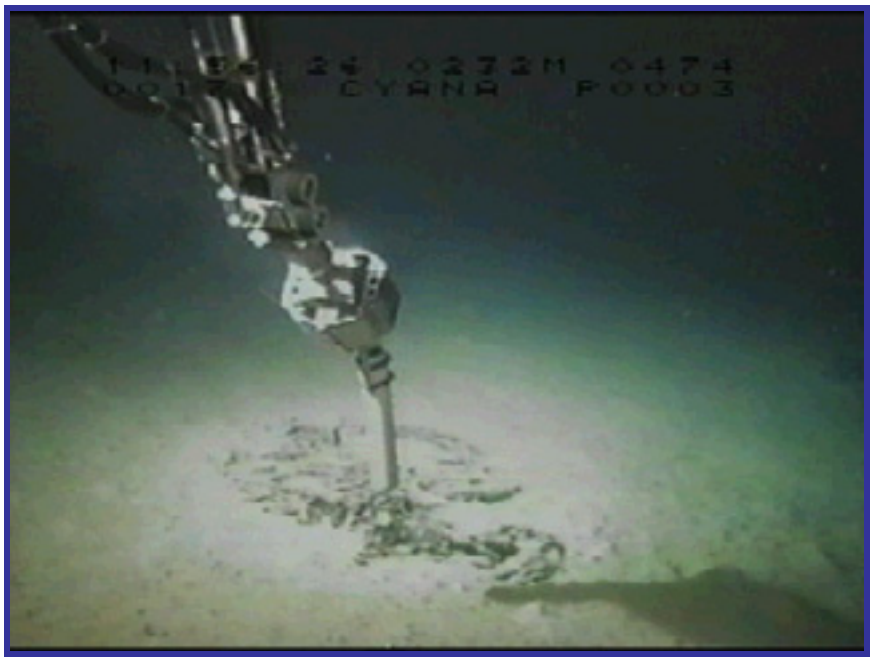


Fig. 6. Bathyal sediment sampling

Table IV. Concentrations of polycyclic aromatic hydrocarbons (μg g^{-1} d.w.) in four subsamples of a sediment core taken during the CYACHUM '94 cruise (1 = surface layer; 2, 3, 4 = sub-surface layers).

	1	***2***	***3***	***4***
Naphtalene	<0.001	<0.001	<0.001	<0.001
Acenaphtene	<0.001	<0.001	<0.001	<0.001
Phenanthrene	0.019	0.005	<0.001	<0.001
Anthracene	0.005	0.002	<0.001	<0.001
Fluoranthene	0.021	0.013	0.004	0.003
Pyrene	0.047	0.003	<0.001	0.001
Chrysene	0.079	0.014	<0.001	<0.001
Benzo(a)anthracene	0.037	0.005	0.004	0.003
Benzo(b)fluoranthene	0.087	0.019	0.005	0.004
Benzo(k)fluoranthene	0.027	0.004	<0.001	<0.001
Benzo(a)pyrene	0.041	0.006	<0.001	<0.001
Dibenzo(a,h)anthracene	0.003	<0.001	<0.001	<0.001
Benzo(g,h,i)perylene	<0.001	<0.001	<0.001	<0.001
Indeno(1,2,3c,d)pyrene	<0.001	<0.001	<0.001	<0.001
TOTAL PAHs	***0.366***	***0.071***	***0.013***	***0.012***

Studies aimed at the evaluation of genotoxic damage and hepatic tissue alterations in demersal fish species sampled in the area (Pietrapiana D. *et. al.*, 2002)[12] show a clear response of *Lepidorhombus boscii* (Fourspotted megrin) to the tar depositions noxiousness for both micronucleus test and liver tissue alterations.

Furthermore, the sea bottom, made up, mainly, of incoherent sediments, had assumed the feature of hard substrata, permitting the settlement and development of species, new for that environment.

At present, two research projects related to the "HAVEN" accident are in progress. The first one aims at studying the fouling populations on the main part of the wreck. In this view, nine frames of 0.125 m^2 have been positioned both on the internal part of the bridge and the external hull within 45 meters depth. Divers are currently taking pictures of the frames at regular intervals of time in order to detect the development of the populations associated.

The second project deals with cageing experiments (mussel watch). Specimen of *Ostrea edulis* are caged and sunk at 40 meters depth nearby the wreck for a three months length of time. Afterwards the organisms are collected and PAHs levels and stress indexes measured and compared with those of other specimen collected from a reference site and directly on the wreck. Results indicate that the specimen living on the wreck and those caged nearby, show, effectively, significantly higher stress and PAHs content (Viarengo A., 2001)[13].

Plans for remediation

In 1999, eight years after the accident, as a consequence of the agreement reached with the IOPCF (Law 239/'98), 16.4 M€ were made available to carry out studies, experiments and restoration interventions and plans can be worked out for remediation.

An agreement was signed among the Italian Ministry of the Environment, ICRAM and the Ligurian Region in order to carry out, through public calls for tenders, a restoration and experimentation project worked out by ICRAM[14] and validated by the main Italian scientific and technical institutions.

Fig. 7. Clean up and experimentation plan guidelines

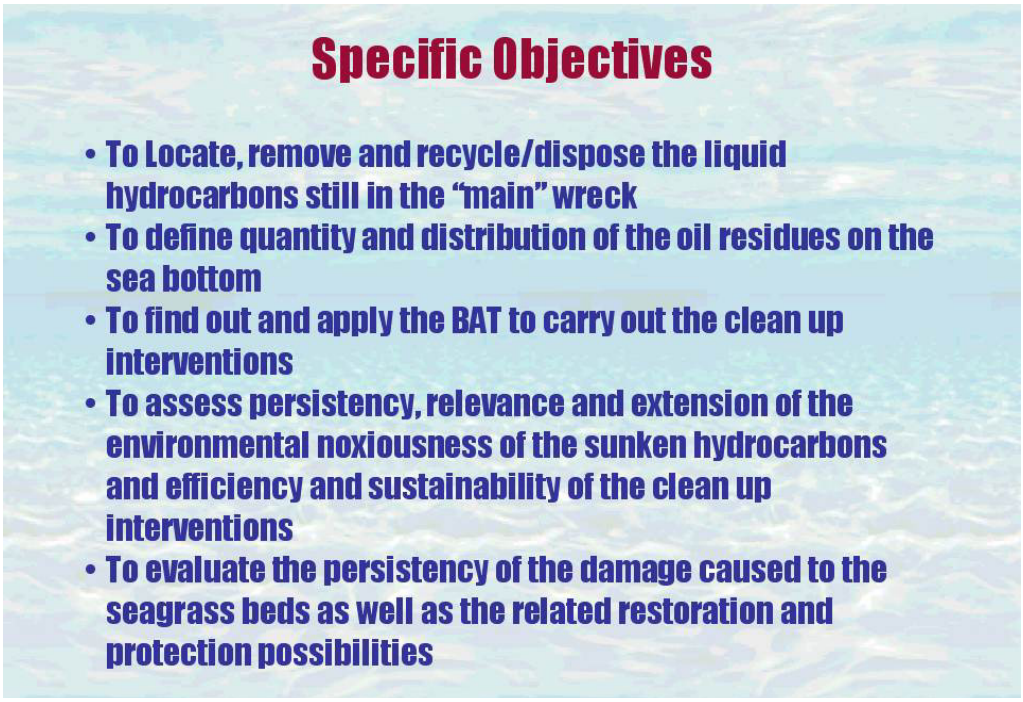


Fig. 8. Clean up and experimentation plan objectives

The plan is mainly aimed at:

- the clean-up from liquid oil residuals of the main part of the wreck;
- the experimental clean-up of part of the sea bottom interested by the presence of tar depositions. To carry out this task, it will be necessary to map the tar depositions, to assess their noxiousness and persistency and to find out the best available clean up

technology. The results will permit to evaluate cost-benefits ratio of an extensive clean-up operation;

- the creation of a data base;
- the re-introduction and protection of *Posidonia oceanica*;
- the elaboration of a long-term monitoring plan.

To carry out the restoration intervention, in accordance with the Italian Law (471/99), it is needed to elaborate:

- Characterization Plan:
  a. Collection of the existing data.
  b. Characterization of the site.
- Preliminary Project:
  a. Pollutant concentrations analysis.
  b. Suitable technologies selection.
  c. Assessment of the environmental compatibility of the intervention.
  d. Tests aimed at to verify the efficiency of the proposed intervention.
- Definitive Project:
  a. Detailed plan of the foreseen work and of the related costs.
  b. *Post-operam* control and monitoring plan.

The first step decided by the committee established by the Liguria Region, ICRAM and Italian Ministry of the Environment agreement, is the clean-up from liquid oil residuals of the main part of the wreck. The task, according with the above outlined framework, among other activities, foresee the detailed inspection of the wreck, recently assigned with a public call for tenders. The case shows to be a difficult one, mainly because of the roominess of the internal structures of the wreck, the location of fuel storage tanks in the double bottom, the turbidity of the water inside close compartments and the depth. Appropriate technologies and methodologies have to be developed and tested in this phase and further studies will be necessary to carry out the clean up of the wreck.

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Author's biography

Dr. Ezio Amato

Master Degree in Natural Sciences, benthic assemblages.

Researcher at ICRAM since 1987, as senior scientist he co-ordinates the environmental impact and damage assessment team. His experience in this field includes the environmental assessment of chemical and oil spills at sea, wreckages and the dumping of conventional and chemical weapons.