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QUANTITATIVE EVALUATION OF WATER BODIES DYNAMIC BY MEANS OF THERMAL INFRARED AND MULTISPECTRAL SURVEYS ON THE VENETIAN LAGOON

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ABSTRACT

This work which is a part of the research effectuated to save Venice and its lagoon, was carried out by remote sensing techniques.
The investigated area is the 'Bocca di Porto di Lido',entrance mouth to the Lido Port which is the most important inlet directly influencing the Historical Center of Venice and the behaviour of an half of the lagoon area.
The aim of this work is to perform a quantitative study of the changing of some parameters with no conventional oceanographic method.
Five surveys (whose repetition rate was one hour) employing a two-channel Daedalus Infrared Scanner and multispectral photography were performed for a complete investigation of spring waning tide.
By means of an electrical analogic technique the thermal signal was analized following the shift of a surface involving two fixed temperature during the tide.
This kind of investigation, repeated for each survey, allowed us to calculate the velocity of water mass under the hypothesis that the lateral thermal conductivity was pratically negligible.
The multispectral photography investigation allowed the discrimination between the different kinds of suspended matter (mainly organic and non-organic).
The sea-thruth on surface was captured by means of local probes with continuous recording of temperature, salinity, sediment transport and ebb stream velocity.
Some considerations about the behaviour of the front of an outgoing "plume" in order to understand the relationship between the two water masses, coming from the northern and Lido lagoonal basins were carried out; this investigation was conducted in order to correlate the bottom topography with the dynamic appearance on the sea surface.

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I. INTRODUCTION AND OBJECT OF STUDY

The Special Law, for safeguarding Venice, stipulated the terms and the conditions for any intervention concerning the regulation of the exchange of internal waters with the sea.
The principal provision considers the reduction of the opening of the port, but since there are still questionable doubts as to the effects of such an act, it was resolved to execute a series of different surveys.
By employing boats various section of the inlet of the Port of Lido were traced to obtain direct measurements of the current velocity and the principal chemical-physical parameters.
All the data were compiled to meet the precise requirements necessary for the formulation and functioning of mathematical and physical models.
A well equipped airborne remote sensing unit, utilized to survey the sea-surface "state" made it possible to integrate the direct measurements to the overall studied area.
Moreover the time-interval surveys accurately described the dynamic phenomena occurring between the lagoon and the sea in terms of their dimension and their evolution.

2. INVESTIGATED AREA

The area under investigation is the Lido inlet (Fig.I), the largest of the three lagoonal entrances (Lido, Malamocco and Chioggia inlets).
Almost 900m wide this hydraulic junction sustains aproximately and inflow and outflow of more than one million cubic meters of water for every tital cycle transporting the waters of Sant Andrea, Sant'Erasmo and Treporti respectively, the latter feeds the entire northern basin.
The depth ranges between 2 to I7m and the greatest depth is found in the south western part of the canal.
For a complete coverage of the area the aerial survey was performed from a constant altitude of I500 m a.s.l. on the axis of the inlet in a south-east and north-ovest direction.
A total of five flights, each at one hour interval starting at II,50 a.m. provided the information enabling a complete study of a syzygial waning tide evolution (Fig.2 the plume flowing between the jetties) (Fig. I dotted square demarcates the investigated area; the arrow indicates the point where direct measurements were taken).

3. METHODS USED

To study the above mentioned phenomena five surveys were simultaneously run in the visible bands (blue, green and red) and in two thermal infrared bands.
Photographs were taken with a "cluster" of three electric Hassblad cameras equipped with Distagon 40mm lenses.
The following film-filter combination were used:

a) B&W Kodak Plus-x film and a 47 Wratten filter (blue band)
b) " " " " " " " 58 " " (green band)
c) " " " " " " " 25 " " (red band)

In the thermal infrared bands a Daedalus scanner model I230 was used.
This instrument provides quantitative data and can be considered as a precise scanning radiometer. In fact, it is provided with two built-in black bodies at constant temperature adjustable in such a way that is makes possible to calibrate the electrical signal.
This is true only if atmospheric absorption is very low or negligible; however, even if atmospheric absorption is considerable this instrument can be employed looking at relative and not absolute measurements.
Very often, in fact as in our case, it is not so important to measure the absolute black-body temperature of the surface as it is to evaluate the differences of black-body temperature between one point and another. Then, since we can suppose with a good approximation that the atmospheric absorption is constant during the test time (a few minutes for each survey) and over the investigated area (3 km) no correction is needed for atmospheric effects.
Two bands of the thermal infrared regions were used and they are as follows:

a) 4.5-5 5 micron with InSb detector
b) 9-II micron with HgCdTe detector

In our case only the 9-II micron band was used since it is the best for the range of temperature under consideration.
Direct measures of "sea-truth" were effectuated from a boat anchored at short distance off of the southern jetty within the entrance of the Port of Lido (arrow in Fig.I).
The parameters surveyed, during the entire waning tide, were as follows: temperature, salinity, ebb stream, velocity and turbidity.
The temperature and velocity data were required for a direct comparison of the values obtained from the thermographic analysis.
Fig. 3 : a) thermography from first flight
b) "slicing" at 6 levels

Fig. 4 : graphic recording of principal chemical-physical parameters measured directly "in situ".

During a time span of seven hours, the turbidity and velocity parameters were continously recorded while temperature and salinity were measured every I5 minutes. Measurements were always made maintaining the probes at the same depth and a minimum distance from the water surface.
Temperature and salinity were measured using a MC5 Electric Switchgear probe with a sensitivity of 0.I ^{o}C and IO ppm.   For turbidity, a Parteck solid suspended monitor with a HP 20 probe based on the principle of differential absorption of light was used with a sensitivity of 2 ppm and a full scale calibrate to 25 ppm.
Ebb tide velocity was surveyed with a unidirectional correntometer model B/8 of the Marina Adviser, with a scale of IO-I5 knots and a sensitivity of 0.I knots.

4. CALCULATION OF SURFACE VELOCITIES

On the possibility of measuring the average waning tide velocity at the sea surface we utilized the space covered by a front of an area at a constant Δ T between one flight and another at one hour interval.
Assuming that thermal exchange of air-water due to the conduction is negligible for this type of calculation; remembering that the Δ T between air and water is minimum the radiation is negleted too.
Of the 5 available thermographs from the five flights were examined only the third and fourth one.
The front of the isotherm area under investigation was situated in the proximity of a point where the sea truth was captured in order to confirm the validity of the method.
The thermography from the third flight (I3,50 p.m.) is represented in Fig.5a, while in Fig.5b, the "slicing" is shown where appears an area involving aΔT.
On Fig. 6a, the thermography from the 4th flight (I4,50 p.m.) is represented and in Fig.6b the"slicing" of the sameΔT precedently considered.
Fig.7 shows a comparison map of the isothermal area boundariės obtained from the two preceding "slicings". On this map, it is shown that the front of the isotherm are advanced in an hour 2200 m corresponding to I.2 knots.
The velocity measurement carried out at the point indicated by the arrow, in Fig.I, gives I.4 knots with a difference of 0.2 knots i.e. I5%.
Such a difference, also present in the errors of the measurements of the traditional oceanographic instruments, is to be attributed to the presence of average wind blowing from the S-E in an opposite direction to the water movement at a speed of about I4 km/hour inhibiting the surface outflow.
Regarding the circulation of the water masses coming from the northern basin it was'nt possible to take reliable measurements since the path of the water current undergoes an abrut change, as shall be seen later on in the hydrodynamic interpretation, so that it is physically impossible to follow the same isotherm level durign one hour.

5. DYNAMIC INTERPRETATION OF THE PHENOMENON

Explaining mouvements of the surface currents is extremely easy with the aid of thermographies. In fact, it is enough to outline the various paths of the isotherm areas to automatically have

a map of the surface's current circulation, using temperature as a tracer.
It is more difficult, even if feasible, to describe the currents paths under the sea surface, taking into account the bathymetry and what occurs at the surface.
In this case, it is just the matter of a precise and accurate interpretation of a physical phenomenon of which the boundary conditions are known.
Even being significant the results of all the flights, it seemed more interesting, for the study of dynamics, those where the velocity of the two water masses (coming from the south and north respectively) is maximum and that happen in the flights 3 and 4 as shown in Fig.7.
In Fig.8, an outline is drawn which represents the probable paths of the two currents, denominated as (N) and (S) before entering into the canal, and then up to the mixing as they are apparent from the surface black body temperatures. On this phase, we have the advantage that (N) and (S) have two very different temperatures ($\Delta T=2.5\ ^{o}C$) so that they are well distinguishable one from the other.
Above all, our attention is focused on the A and B points (see Fig.8).
At point A, a thermal discontinuity is so strong to be only explained by hydraulic considerations that is current (N) flows under current (S).
At point B, a water mass colder than the surrounding water is detected at the surface which could float only if its density were less than that around it, that is to say a very low salinity.
The above described dynamic behaviour is confirmed taking into account a bathimetric profile shown in Fig.IO, where it is very easy to observ a thermocline (arrow) testifying the existance of two water masses with two different physical characteristics, floating in the forseen location.
As we can see in Fig.8 and 9, we find at point C, just slights after the immersion of (N) under (S), a lowering of the bottom unjustifiable if it was not for the erosion associated with current (N).
Lastly, we can see that the geometry of the bathymetry near the two light houses at the end of the jetties are somewhat diverse. It could even be in this case an effect of accelerated erosion induced by current (N) that therefore affects point (D), in comparison to that relative to point E.

6. CONCLUSION AND FINAL CONSIDERATIONS

As already mentioned in the introduction, this work was executed by using an unusual survey technique for the circulation data and as shown from the results presented this kind of approach seems particularly good for this type of phenomena.
The positive and negative aspects of this technique are briefly summarized as:

I) synopticity of the survey: it is evident that in noway ground measurements even plentiful can reach a synthesis so complete from only one survey

2) precision of measurements: absolute temperature measurements are not allowed (whose interest is relatively scarce). Relative measurements are possible with a precision up to at least $0.2\ ^{o}C$ which seems to be the limit even for the traditional thermometers

3) possibility of extended investigation : when the aircraft is in flight, the cost increment of an investigation in a near zone is extremely low

4) possibility of various investigations: for the same reason just stated above, it is cheaper to load the plane with as many instruments as possible, thereby gathering the maximum data with the minimum of cost

5) impossibility of using the thermal infrared bands to investigate underneath the surface: this is due to the nature of the electromagnetic radiation in that wavelenght

6) the use of temperature as a tracer is feasible, but we can't (for obvious thermal exchanges with the surroundings) study from the air extremely large areas. This will be possible when the thermal sensors on board the satellites will have a thermal and geometric resolution useful for these scopes

6) for the following investigations it could be good to effectuate for every scheduled survey

at least two flights over the same area a few minutes apart, to catch small but significant movements of the water masses

7) taking into account the wind effect it is advisable that these surveys has to be carried out in the absence of wind or at least when blowing at a constant speed as in our case.

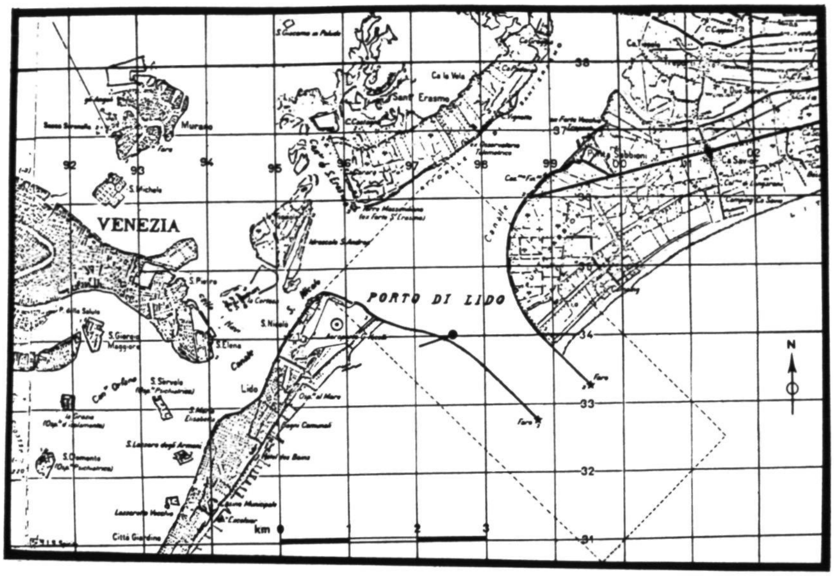

Fig. 1. The investigated area.

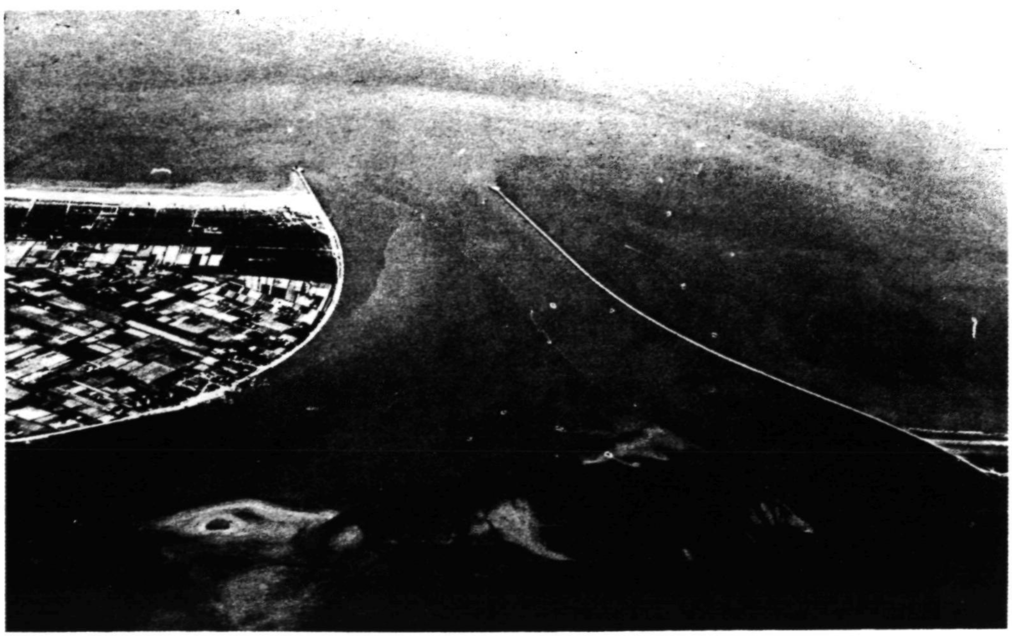

Fig. 2. Aerial photo of the plume.

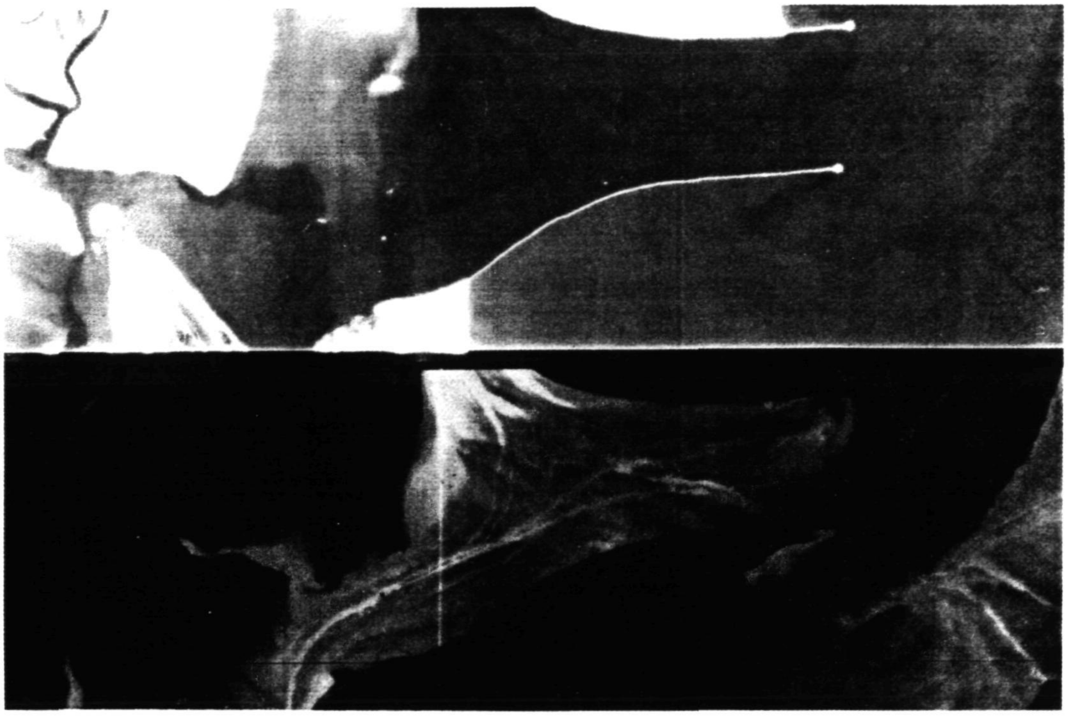

Fig.3. Thermography of the first flight (up)
Level slicing of the previous thermography (down).

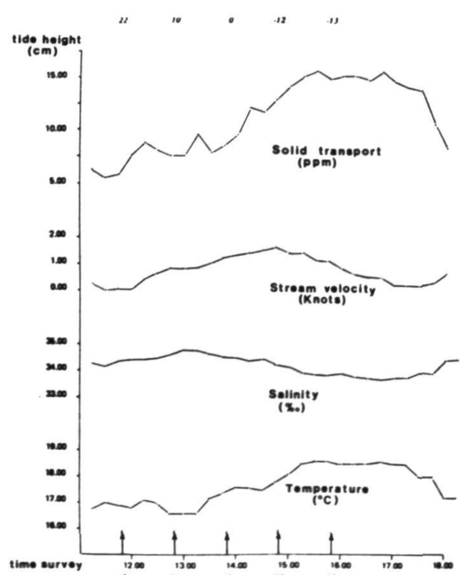

Fig.4. The four parameters recorded "in situ"
(see arrow in fig. 1).

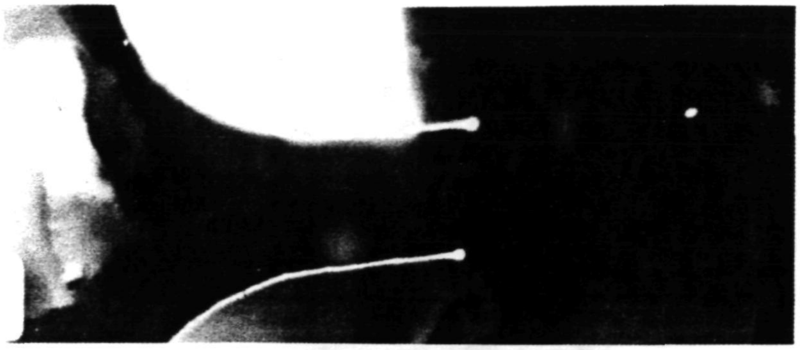

Fig. 5. Thermography of the 3^{rd} flight (up).
The level slicing used for the velocity calculation.(down)

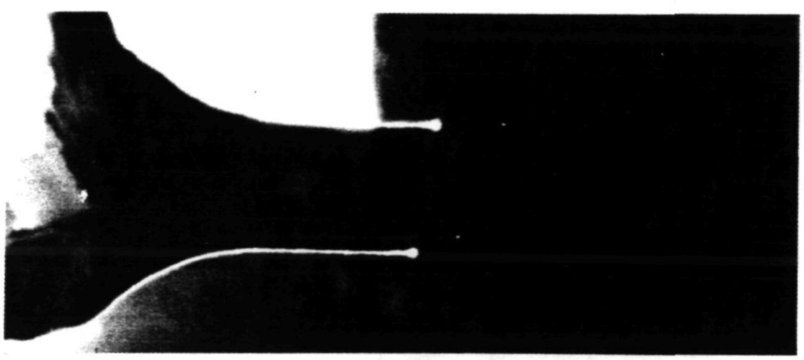

Fig. 6.Thermography of the 4^{th} flight (up)
The level slicing used for the velocity calculation (down)

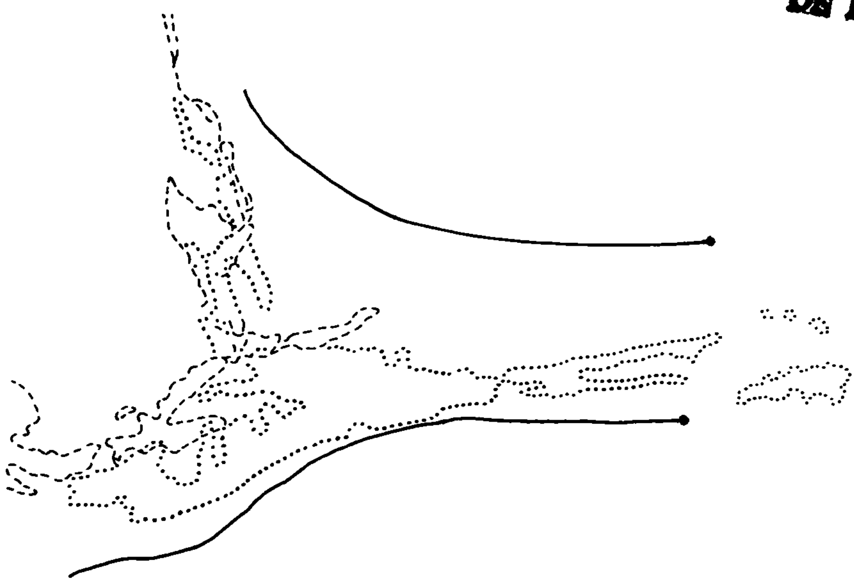

Fig. 7. Comparison between the boundaries of the isolevels of the 3rd and the 4th (dotted) surveys.

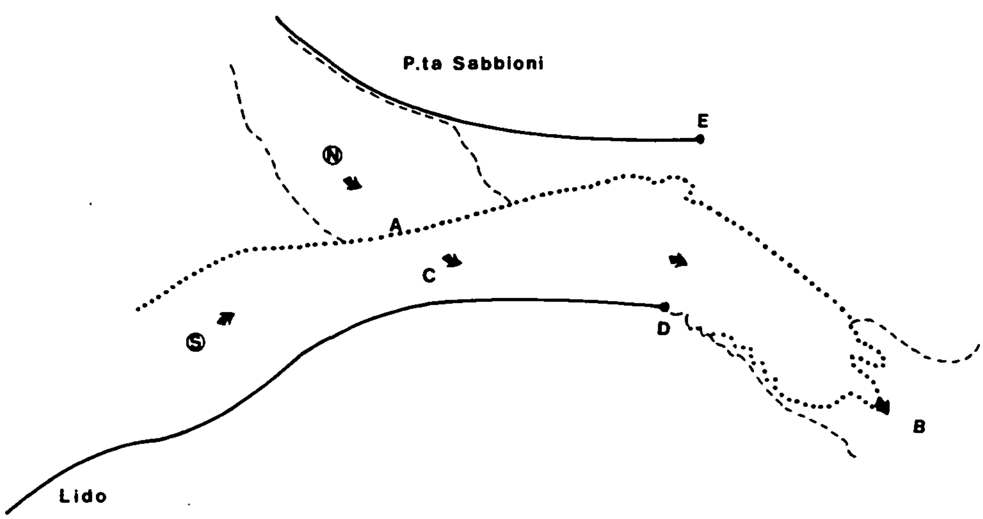

Fig. 8. Map of the dynamics of the two water bodies.

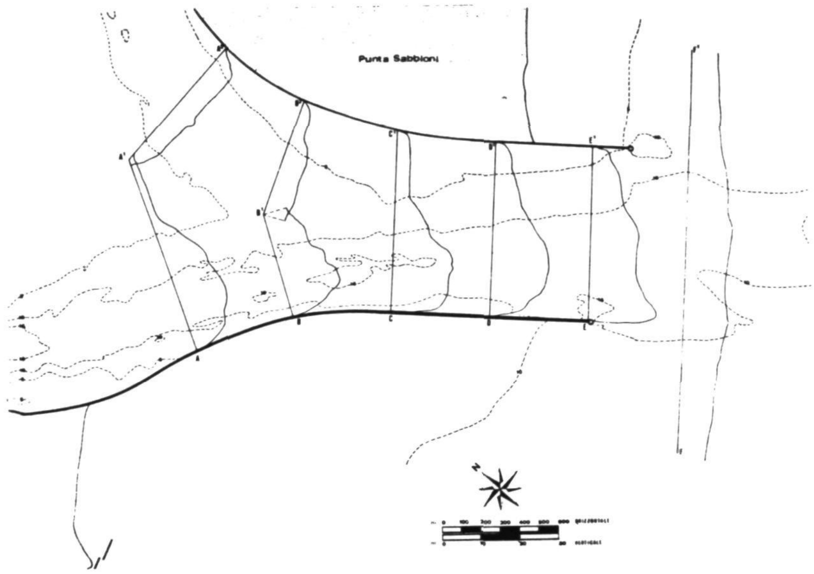

Fig. 9. Cross bathymetric prophiles of the inlet.

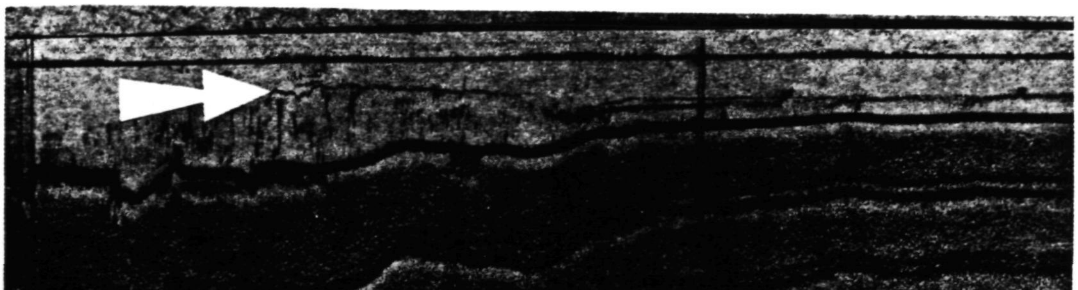

Fig. 10. On-axis bathymetric sonar survey of the southern part of the inlet.