

The sediment's role in the management of the beach and the recreational use of water

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ACeS PROJECT

Water Climate and Health

From the environmental protection of resources,
to access to water, to safety of use

The environmental legislative context

EUROPEAN LEGISLATIVE FRAMEWORK

- **2006/7/EC**, in line with Directive 2000/60/EC, is specifically **focused on the quality of bathing water**, aims to provide a bather protection approach based on monitoring and risk prevention by addressing the main sources of contamination and routes of spread.

This Directive does not provide procedural indications for pollution other than the microbiological one and for matrices other than water.



TRANSPOSITION IN ITALY WITH

- Legislative Decree 116/2008
- Implementing Decree of 30th March 2010, which defined the specific criteria for bathing bans, the reference limits for water quality, and the technical procedures.

Sediments are still not considered in the evaluation of the bathing water

Why consider also sediments? But not only them...

Marine sediments are composed of sand, silt, clay, and organic materials, along with a biological component represented by bacteria. Bacteria decompose organic matter and play an essential role in biogeochemical cycles, such as those of carbon and nitrogen.

They also serve as a long-term reservoir of many types of particles and harmful substances resulting from human and natural activities (resistant forms of toxic algae), representing a secondary source of contamination that, under certain conditions, can release various hazardous substances into the aquatic environment.



As filter-feeders, bivalves accumulate contaminants present in the water, such as bacteria, viruses, and chemicals, making them a kind of natural "alarm" for pollution. They act as biological indicators and natural water filters, and so, they are important for assessing the quality of coastal marine environments.

Pollution of beach and marine sediments

The need to consider chemical and microbial pollution of beach and the close seabed sediments has increased in recent years in the assessment of the quality of bathing areas, not included in standard monitoring

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DISCUSSION

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Marine pollution: Let us not forget beach sand

Francois Galgani¹, Katrin Ellerbrake², Elke Fries^{2*} and Chantal Goreux³

*Assessing the chemical or bacterial contamination in marine waters and sediments is a very common approach to evaluate marine pollution and associated risks. However, **toxicity and organic pollution of beach sands have not yet been considered**, except in adjacent waters.*

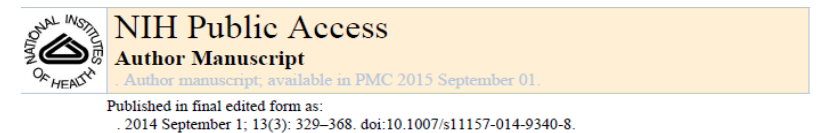
The first evidence of toxicity and the presence of organic contaminants in beach sands raises important questions that need to be addressed in the future by the scientific community.



Microbial pollution characterization of water and sediment at two beaches in Saginaw Bay, Michigan

Amira Oun, Ziqiang Yin, Mariya Munir, Irene Xagorarakis *

*Recently, there is increasing concern about **sediment as a source of beach water quality impairments**. Several studies have confirmed occurrences of *E. coli* and enterococci being higher in sediment than overlying water, as well as the **potential of sediment to act as a reservoir for fecal** organisms. FIB-contaminated beach sediments can act as diffuse FIB sources. FIB from sand in a California beach were mobilized by rising tides*



Microbes in Beach Sands: Integrating Environment, Ecology and Public Health

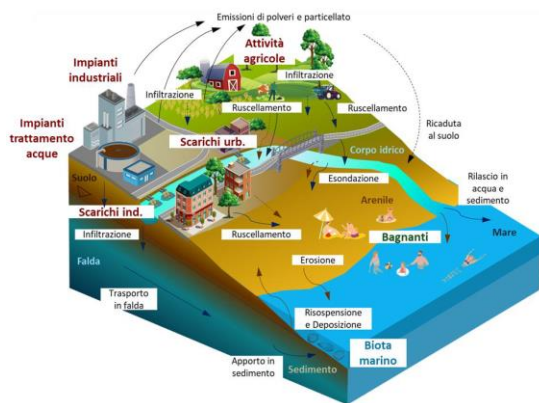
Richard Whitman¹, Valerie J. Harwood², Thomas A. Edge³, Meredith Nevers¹,

*The concept of beach sand as a microbial habitat and reservoir of FIB and pathogens has begun to influence our thinking about human health effects associated with sand exposure and recreational water use. A variety of pathogens have been reported from beach sands, and recent epidemiology studies have found some evidence of health risks associated with sand exposure. **This review concludes with recommendations for future work in this vastly understudied area.***

The ACeS Project

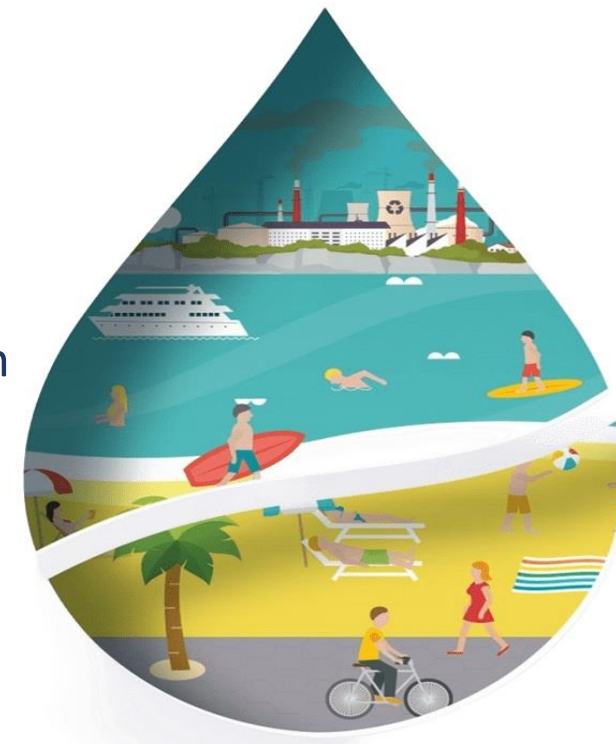
GOAL OF THE PROJECT

- Improve the knowledge on the interactions of different environmental matrices (water, beach and marine sediments, biota) and their correlation with some chemical contaminants, but also emerging pathogens (including antibiotic-resistant ones)
- Provide useful scientific data for the management of bathing areas



ADOPTED STRATEGY

- 2 different sites (Adriatic and Tyrrhenian Sea) influenced by different types of pressures: industrial activities, urban discharges, and agricultural runoff
- water, sediment and organisms investigated before, during and after the bathing season
- Textural, chemical, microbial and ecotoxicological characterization approach



ACeS PROJECT

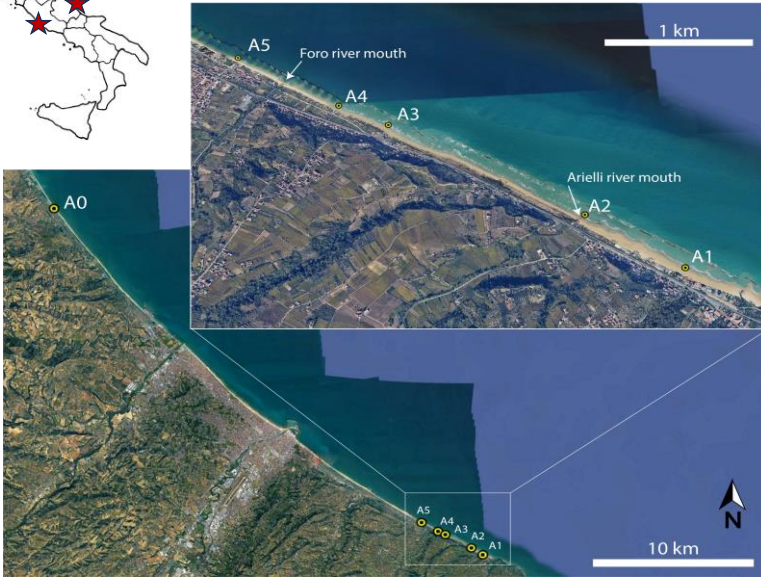
Water Climate and Health

From the environmental protection of resources, to access to water, to safety of use

PNC (National Complementary Plan)

Public national funds, managed by the Italian government, dedicated to financing research and innovation as a complement to the EU PNRR (National Recovery and Resilience Plan)

Study areas and monitoring plan



The **Tyrrhenian coastline** between Focene and Passoscuro (Fiumicino, Rome). The bathing waters are classified as being of excellent quality. However, some potential pressures are present in the area of influence: in the northern sector, the Arrone River that collects runoff from agricultural land; in contrast, in the southern sector, a discharge point of mixed waters is present.



The **Adriatic coastline** (Ortona, CH) is designated for bathing use, from the mouth of the Arielli River to the mouth of the Foro River. This area is the most critical of the Abruzzo coast because bathing water quality was classified “poor” for five consecutive years. Consequently, a permanent bathing ban has been imposed for the 2024 close to the Arielli River and Foro River mouths.

n. 3 sampling campaigns over the two years (2024 and 2025):

- May
- July
- September

n. 5 stations in each area on about 10 km of coastline

- n. 1 surface water sample
- n. 1 beach sediment sample
- n. 1 seabed sediment sample

n. 1 control station with the same samples
Filter-feeding organisms' representative of each area:

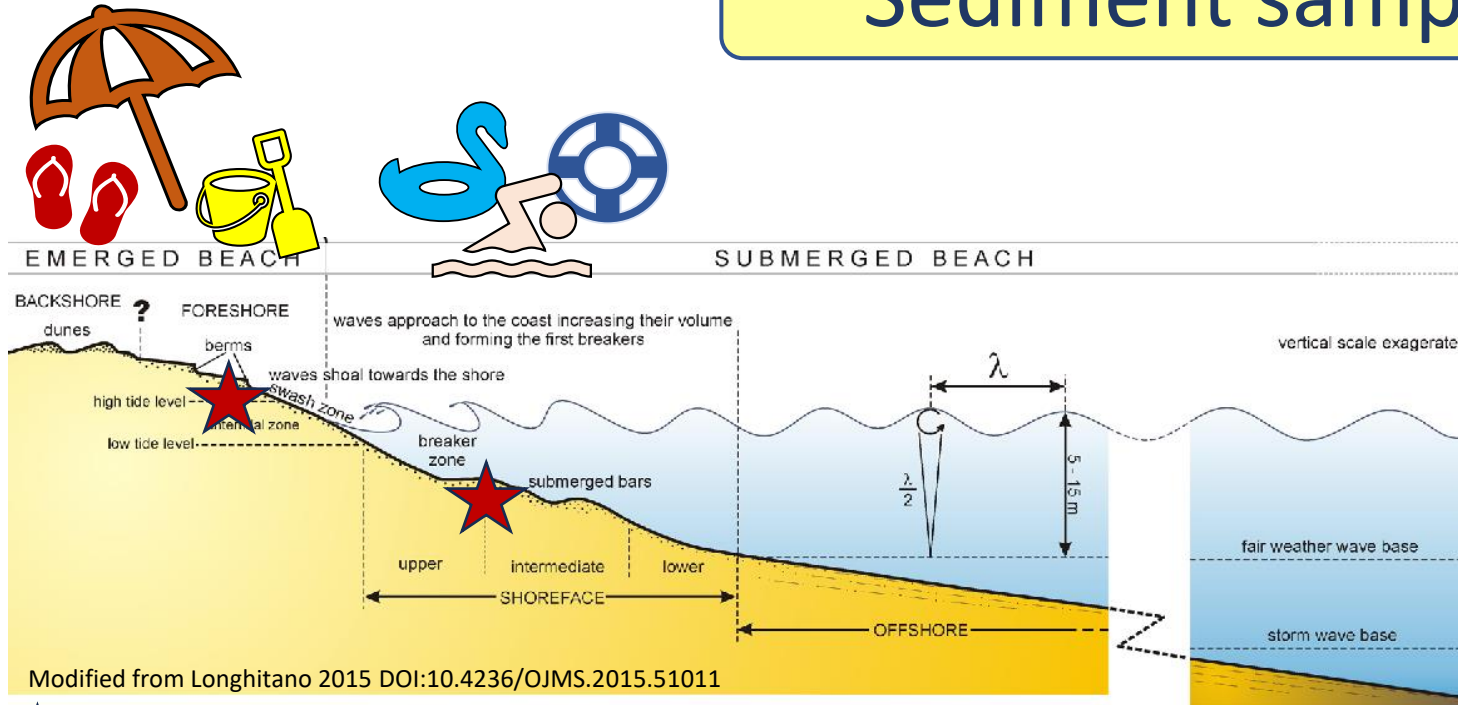
- *Donax trunculus* for the Tyrrhenian Sea
- *Chamalea gallina* for the Adriatic Sea

Analyses

MATRIX	ANALYSIS TYPE	PARAMETERS
WATER	Chemical analysis	Cd, Cu, Hg, and Pb; Antibiotic resistant
	Microbiological analysis	<i>E. coli</i> , intestinal enterococci, <i>Salmonella</i> spp., <i>Norovirus</i> , Hepatitis A and E
	Biomolecular analysis	eDNA
BENTHIC ORGANISMS	Chemical analysis	Hg, Cd, and Pb; Polycyclic Aromatic Hydrocarbons (PAHs); Polychlorobiphenyls (PCBs), Dioxins
	Microbiological analysis	<i>E. coli</i> , <i>Salmonella</i> spp., <i>Listeria</i> spp., ESBL resistant bacteria, <i>Norovirus</i> , Hepatitis A and E
	Biomolecular analysis	Metagenomics and Resistome
BEACH AND MARINE SEDIMENTS	Physical analysis	Grain size
	Chemical analysis	As, Ba, Cd, Co, Cr, Cu, Fe, Hg, Mg, and Pb, PAHs, PCBs
	Ecotoxicological tests	Battery of three test organisms belonging to different trophic levels
	Microbiological analysis	<i>E. coli</i> , intestinal enterococci, <i>Salmonella</i> spp.

Water chemicophysical parameters with CTD probe

Sediment sampling



★ Sampling points



BEACH SEDIMENTS –
Manually sampled with
a steel spoon, no
replicates.

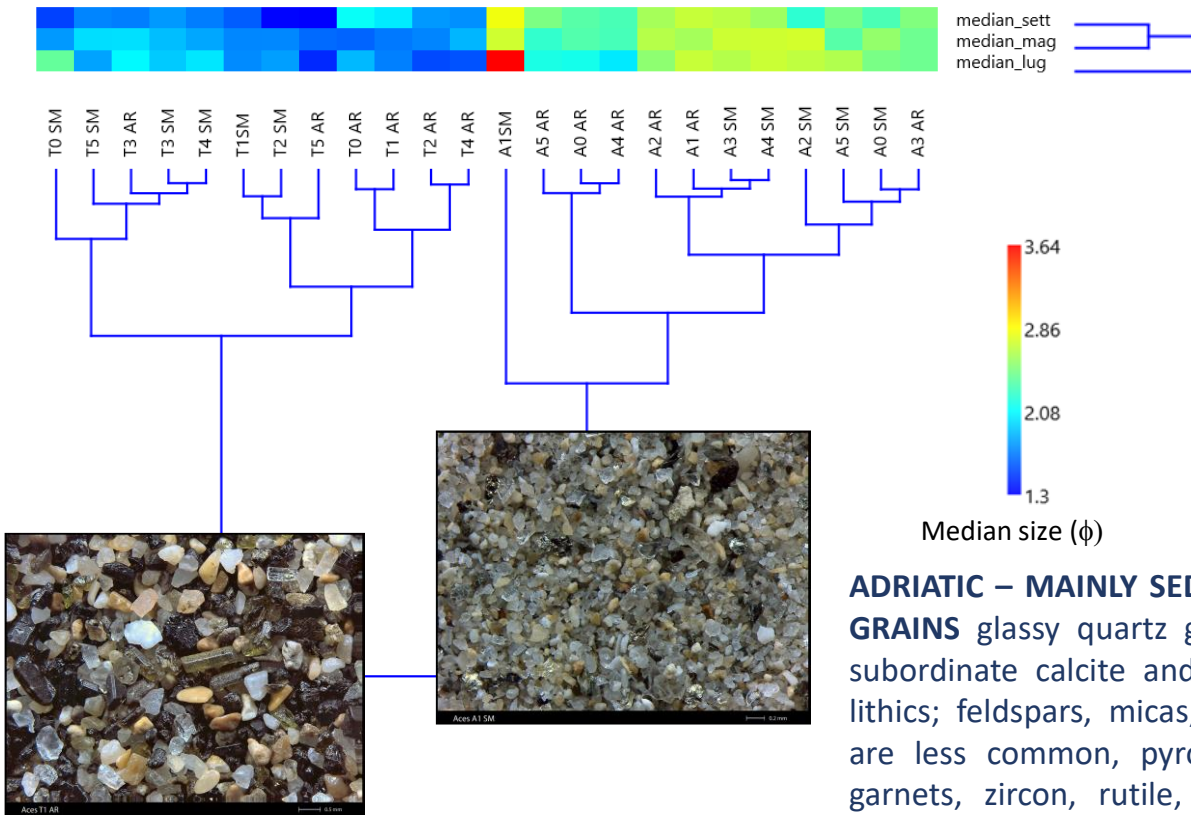


MARINE SEDIMENTS from the submerged beach – Three replicates with van Veen grab

At each sampling station, two samples were collected, one of **beach sediment** on the emerged beach (foreshore), and one of **marine sediment** on the permanently submerged beach, at about 1 m water depth. **These two sectors are characterized by a bidirectional sediment flow, with possible redistribution of pollutants.**

In low-energy conditions, waves transport sand from the foreshore to the backshore. This leads to the accumulation of material in the upper part of the beach and the formation of berms. In high-energy conditions, waves erode sand from the backshore and move it toward the foreshore or even further offshore.

Sediment characterization



TYRRHENIAN – MAINLY VOLCANIC GRAINS

quartz, feldspar, pyroxene, calcite, and biotite, associated with more sporadic volcanoclastic and sedimentary lithics, muscovite, olivine, magnetite, zircon, and garnet. Scarce bioclastic fraction.

ADRIATIC – MAINLY SEDIMENTARY GRAINS glassy quartz grains, with subordinate calcite and carbonate lithics; feldspars, micas, and chert are less common, pyroxenes and garnets, zircon, rutile, magnetite, and kyanite are rarer. Sporadic bioclastic fraction.

According to the Shepard classification, all the samples from both areas are SAND and no changes were recorded among sites and through time.

Considering the median grainsize, the two-way Hierarchical Cluster Analysis highlighted two main clusters:

Tyrrhenian samples - coarser grainsize (medium sand)

Adriatic samples - finer grainsize (fine sand)

In each cluster, only minor differences were recorded mainly attributable to the location on the emerged beach or seabed (submerged beach).

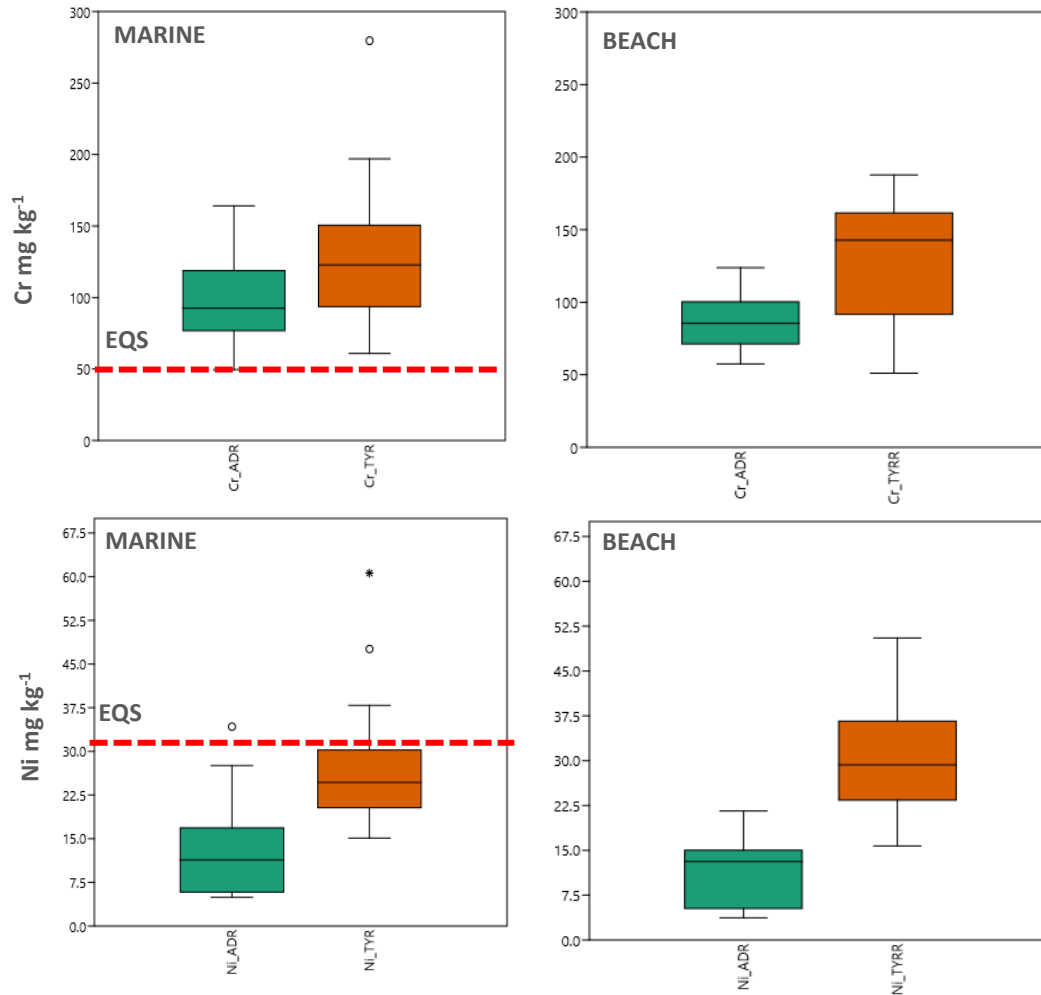


The compositional and dimensional differences between the two areas point to different hydrodynamic conditions and sedimentary sources

The high compositional and dimensional similarity of beach and marine sediment in each area indicates an effective bidirectional flow of sediment between the beach and the close seabed

Sediment chemical characterization

Tyrrhenian Sea
Adriatic Sea



Environmental Quality Standard (EQS) D.Lgs. 152/06.

Most chemical parameters did not show significant contamination

Cr showed high concentrations in beach and marine sediments at all stations from both the Adriatic and Tyrrhenian sites, ranging from 164 to 280 mg kg⁻¹. High values during all seasons in the two areas could be explained by **diffuse contamination along the coast**.

Ni was found to be moderately high, up to 61 mg kg⁻¹, only in the **Tyrrhenian** samples collected in May 2024. This fact points to a **slight contamination determined by seasonal factors**.

In each area, the distribution of both Cr and Ni concentration ranges are well comparable in beach and marine sediments

It suggests that the dynamic interactions between the emerged and submerged beach are effective for the distribution of heavy metal contamination

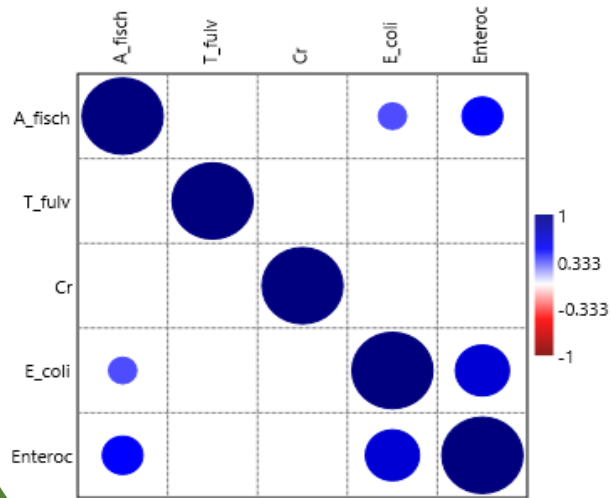
Sediment ecotoxicology

The *Phaeodactylum tricornutum* test showed **no evidence** of toxicity.

The *Aliivibrio fischeri* test indicated **moderate toxicity** at 2 stations (A3 and A4) in Adriatic Sea and 1 in the Tyrrhenian Sea (T5) in May 2024.

The *Tigriopus fulvus* test indicated **moderate toxicity** in Tyrrhenian Sea: T1 in July 2024, and at all stations except T5 in September.

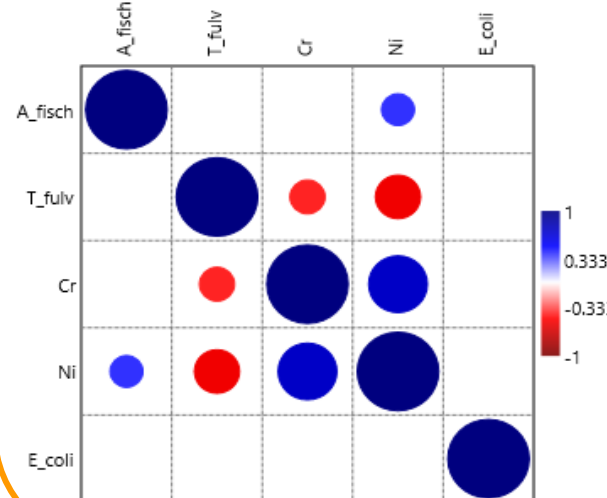
ADRIATIC SEA – recognized contaminants are Cr, *E. coli*, and Enterococci



Positive correlation of *A. fischeri* (% inhibition) with both Enterococci and *E. coli*

Microbiological contamination has toxic effect

TYRRHENIAN SEA – recognized contaminants were Cr, Ni, and *E. coli*



Positive correlation of *A. fischeri* (% inhibition) with Ni.

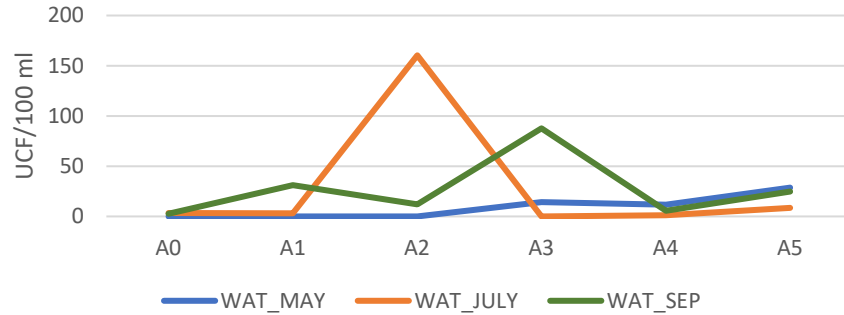
The negative correlation of *T. fulvus* with Cr and Ni could not be a biological effect, but a “statistical effect”

Ni contamination seems to have a toxic effect

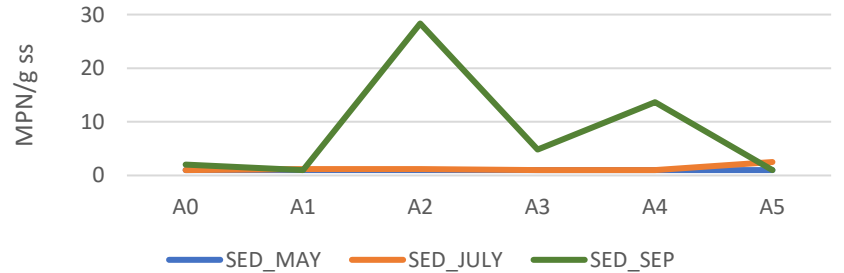
Correlations between contaminants and ecotoxicological results provide information on the possible responsibility of sediment toxicity

Microbiology in sediment and water

E. Coli +
Enterococci
in WATER



E. Coli +
Enterococci
in SEDIMENT



A significant microbiological contamination was recognised only in the Adriatic area

May 2024 - Absence of pathogenic bacteria in sediments and water

July 2024 - *Escherichia coli* was recorded in sediments only at A2, close to the Arielli River mouth. At the same station, the highest values for *E. coli* and the presence of *Salmonella* were recorded in water.

September 2024 – Sediment contamination by *E. coli* and Enterococci between A2 and A5 stations, with the highest values at A2. The same distribution was observed for water contamination, but with lower values than in July

These results suggest that sediments act as a sink and that are a conservative matrix for microbiological contamination supplied through water contributions



Bioaccumulation

The bioavailability of some contaminants was studied by means of bioaccumulation in two autochthonous species of bivalves typical of the Adriatic and Tyrrhenian areas, respectively

ADRIATIC

All samples tested negative for dioxins, PCBs, PAHs, and trace metals.

The samples were found to be compliant with the limit of the Italian legislation (Regulation 2073/2004, 230 MPN/100 g) for the microbiological parameters *E. coli*, *Salmonella* spp., *Listeria monocytogenes*, *Vibrio cholerae*, *Vibrio parahaemolyticus*, and *Vibrio vulnificus*.



Chamalea gallina

Only 1 sample was collected in 2004 for the Tyrrhenian area. It tested negative for dioxins, PCBs, PAHs, and trace metals. *E. coli* was positive (490 MPN/100 g), exceeding the limit permitted by Italian legislation (Regulation 2073/2004, 230 MPN/100 g).

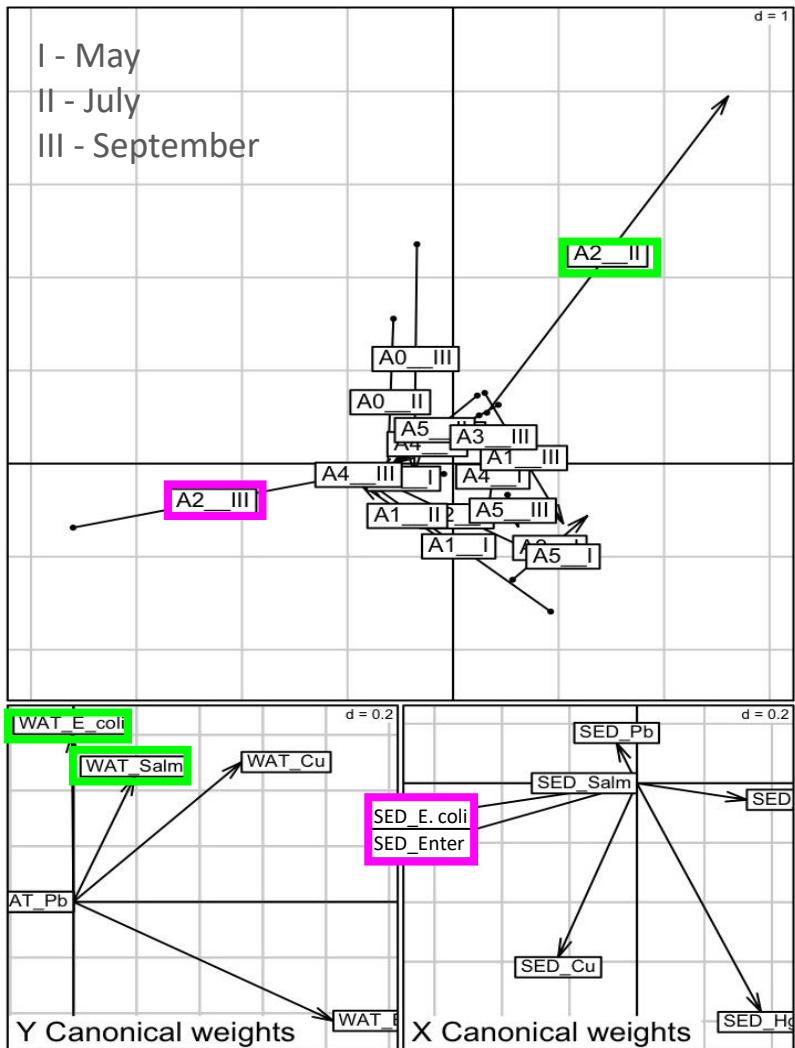
The sample tested negative for *Salmonella* spp., *Listeria monocytogenes*, *Vibrio cholerae*, *Vibrio parahaemolyticus*, and *Vibrio vulnificus*.

TYRRHENIAN



Donax trunculus

Interaction between sediment and water – Adriatic Sea



The Coinertia Analysis (CA) was applied to compare the results of **the same parameters from two environmental matrices, sediments and water**, putting two distinct factorial analyses on the same factorial plain.

No relationships between matrices were evident for trace elements (Cd, Cu, Hg, and Pb). The concentrations of elements both in sediment and water were at natural concentration and no anthropogenic contribution was recognised.

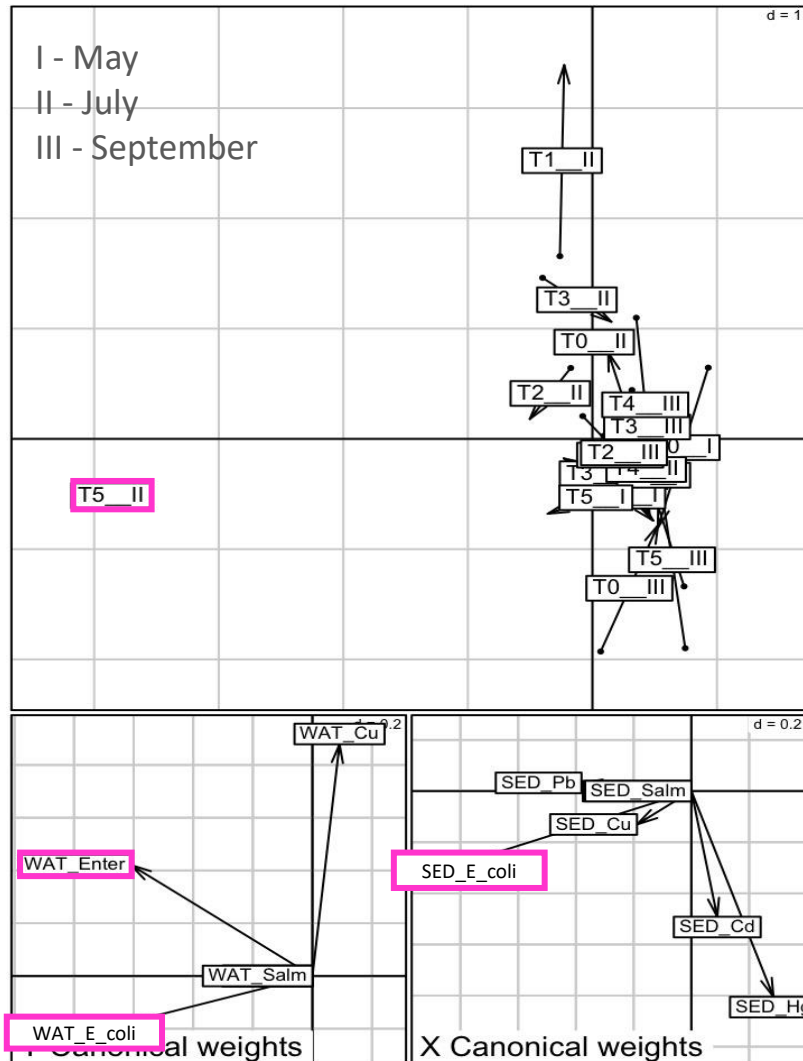
A2_II (July) is the most contaminated station for water, due to the highest values of *E. coli* and the presence of *Salmonella*.

In September (**A2_III**), the most contaminated matrix in A2 is sediment, due to *E. coli* and Enterococci, but not *Salmonella*.

The analysis supports the observations made on the microbiological contamination that recognized station A2, close to the Arrone River mouth, as the most contaminated one, with differences among seasons and matrices.

Moreover, it points to the role of sediments as sink for microbiological contamination due to *E. coli* and Enterococci, supplied by riverine water during the bathing season and persistent in sediments after the end of it.

Interaction between sediment and water – Tyrrhenian Sea



The Coinertia Analysis (CA) was applied to compare the results of **the same parameters from two environmental matrices, sediments and water**, putting two distinct factorial analyses on the same factorial plain.

No relationships between matrices were evident for trace elements (Cd, Cu, Hg, and Pb). The concentrations of elements both in sediment and water were at natural concentration and no anthropogenic contribution was recognised.

T5_II (July) is the most contaminated station both for water, due to the highest values of *E. coli* and Enterococci. Other stations do not show evidence of such contamination

The analysis shows that microbiological contamination is supplied by water contributions of the Arrone during the bathing season, and that it is locally stored in sediments, but it does not persist in September.

A possible explanation of this difference with respect to the Adriatic, to be verified by further studies, is the coarser sediment grain size in the Tyrrhenian area.

Preliminary consideration

- Grain size analyses of sediments provide information on origin and hydrodynamic conditions
- Chemical and microbiological contamination can affect the sandy sediments of the beach and the seabottom in the bathing belt, despite the absence of fine sediment fractions
- An effective bidirectional flow of sediment between the beach and the close seabed determines a redistribution of contaminants
- Heavy metal contamination is not correlated with grain size
- The contaminants responsible for the sediment toxicity may be recognised through statistical correlations
- As regards microbiological contamination, a close interaction between water and sediment has been recognised because marine sandy sediment resulted the final sink and conservative matrix for such contaminants supplied by riverine waters

A holistic approach, considering the deep interaction of the three matrices, sediment, water, and biota, is necessary for assessing the environmental quality of bathing areas for management purposes aimed at avoiding risk for human health

Thank you for your attention!

