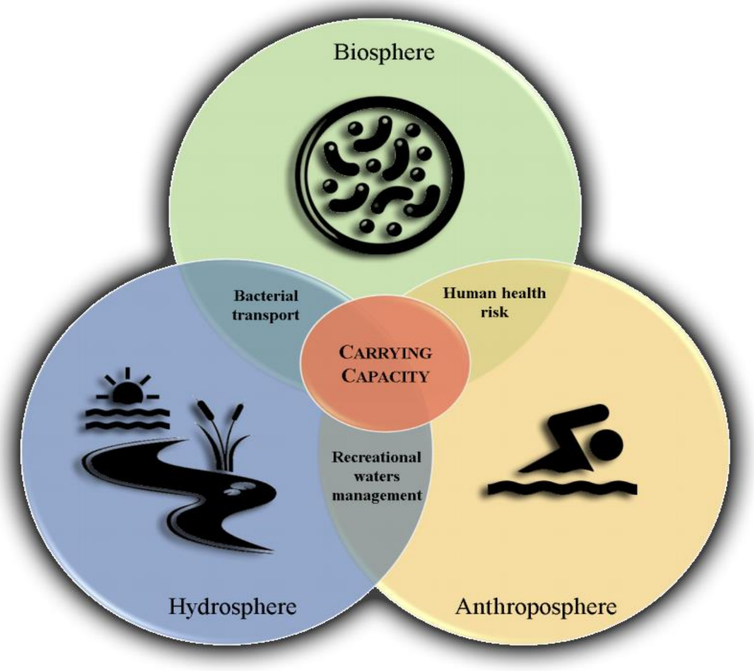

Why should we care about Carrying Capacity?

A novel screening tool for the health risk in recreational waters near estuary

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Introduction

The concept of Carrying Capacity of recreational beaches

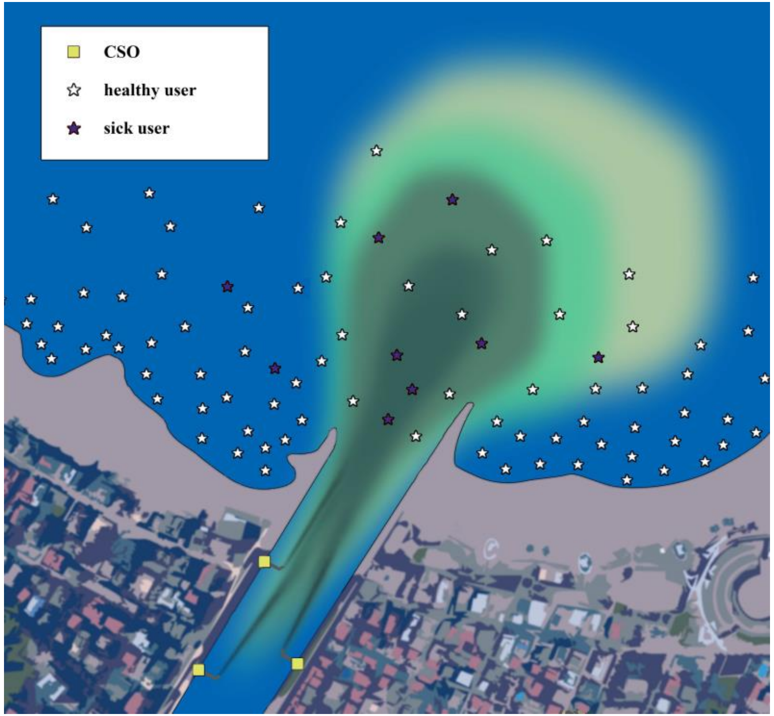

Figure 1: Conceptual framework illustration of source-pathway-receptor approach, where source is represented by several Combined Sewer Overflows (CSOs), the pathway is the river-buoyant plume, while swimming users are receptors (represented by stars).

- Our environmental target is a beach resort near an estuary.
- The river is affected by sewage wastewater spilled by Combined Sewer Overflows (CSOs), which are triggered when sewage exceeds the capacity of the sewage treatment plant.
- Several studies observed a correlation between accidental ingestion of sewage-contaminated water and symptoms of gastrointestinal illness [1,2,3].
- Contamination affects the coastal water quality. Indeed, some beach users (represented in Figure 1 with stars) may develop adverse health issues.
- Here, we aim to address the *relationship* between the ***bacterial concentration*** and the ***Carrying Capacity***, *i.e. the sustainable number of healthy users.*

Case of study
City of Rimini (Italy)

Figure 2: The city of Rimini in Italy, from Google Maps

Target

- Touristic beaches near estuary of Marecchia River (Risk of infection through bathing activities)

Main sources of contamination:

- Contamination resulting from industrial and agricultural activities in Marecchia basin
- *The urban drainage system of Rimini is inadequate. Enteric bacteria (E. Coli, Enterococci) are spilled in the estuary [4,5]*

Microbial concentration at Marecchia
The effect of Rainfall

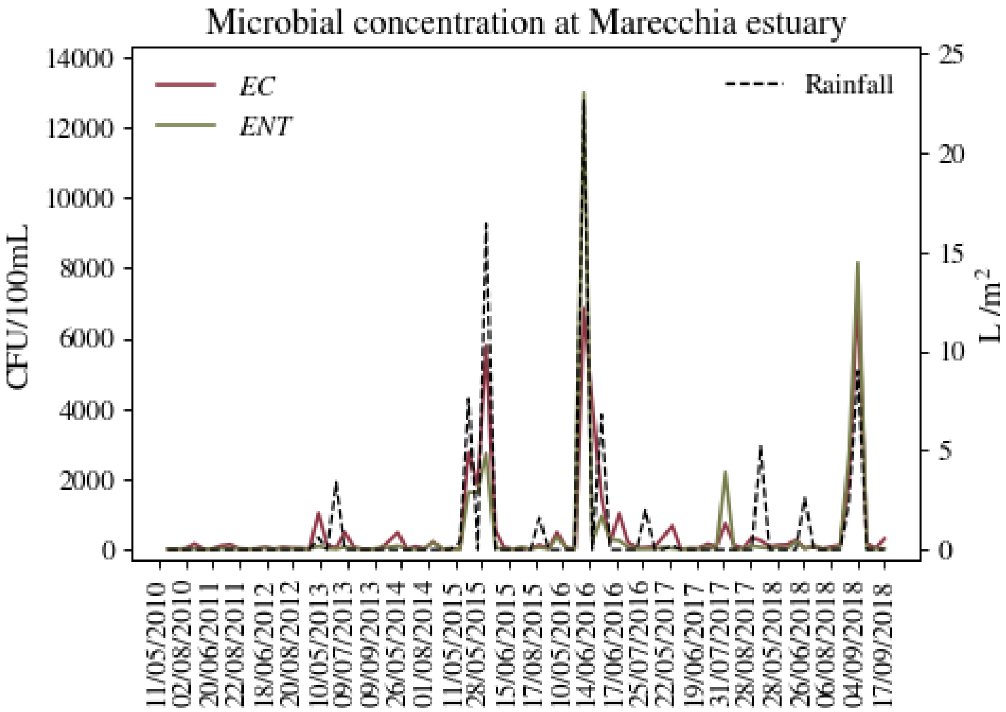

Figure 3: Bacteria concentration measured at the Marecchia Estuary during the summer season (May to September) from 2010 to 2018 from ARPA Emilia Romagna

- International environmental agencies [6,7] recommend to use E. Coli (EC) and Enterococci (ENT) as indicators of gastroenteritis-related pathogens.
- Following the recommendations of the *E.U. Bathing Water Directive* [6], the Regional Environmental Agency of Emilia Romagna (ARPA) monitors the quality of marine recreational waters during the summer season, which spans from May to September.
- Data (Figure 3) show steep peaks with high load values (about 1,000 - 10,000 CFU/100mL), corresponding to severe rainstorm events (confirming that the marine water contamination is mainly caused by the inefficient urban sewage system).

Mathematical Framework
Exposure Assessment

The exposure assessment aims to quantify the daily dose *D* [CFU]
(the amount of bacteria that one individual assumes during a single exposure in a day).
The expression depends on microbial concentration, ingestion rate and exposition time, as follows: [8]

$$D_i = c_i \, r_{ing} \, t_{exp}$$

Microbial concentration [CFU/100mL]

$$c_i \quad \text{where } i = (ENT, EC)$$

The microbial concentration is determined by making use of the ***spatially integrated statistics***, which is a *transport model* originally developed for atmospheric turbulent flows [9] and recently applied to coastal and estuarine environments [10].

Ingestion rate [mL/hr] [11]

$$r_{ing} = 21 mL / hr$$

Exposition time [hr] [12]

$$t_{exp} = 0.75 \, hr$$

Mathematical Framework

Quantitative Microbial Risk Assessment (QMRA)

The number of beach users CC is a function of the daily gastrointestinal risk associated with the ingestion of E. Coli (EC) and Enterococci (ENT) [13]

$$CC = \frac{\ln\left(1 - R_t^*\right)}{\ln\left(1 - R_t^{'}\right)}$$

$R_t^{'}$ - The daily single-user risk (daily single-user risk for combined effect of EC and ENT)

R_t^* - The acceptable level of total-users risk

The daily risk to contract gastroenteritis, $R_t^{'} = R_{ENT}^{'} + R_{EC}^{'} - R_{ENT}^{'} R_{EC}^{'}$ when ingesting of a dose D of relevant bacteria (ENT or EC), can be quantified as the probability that at least one organism will start an infection [8]. The relationship between D and Rt (gastroenteritis occurrence) is assessed through a dose-response model. The Dose-Response Relationships for both ENT and EC are given by:

Dose-Response Relationship for Enterococci

- Exponential Dose-Response Relationship [14]

$$R_{ENT} = 1 - \mathrm{Exp}\left(-k_{DR} D_{ENT}\right) \qquad k_{DR} = 18 \times 10^{-5}$$

Dose-Response Relationship for E. Coli

- Beta-Poisson Dose-Response Relationship [15]

$$R_{EC} = 1 - \left[1 + \frac{D_{EC}}{N_{50}}\left(2^{1/\alpha} - 1\right)\right]^{-\alpha} \qquad \alpha = 0.175 \qquad N_{50} = 2.55 \times 10^6$$

Results
Total Risk

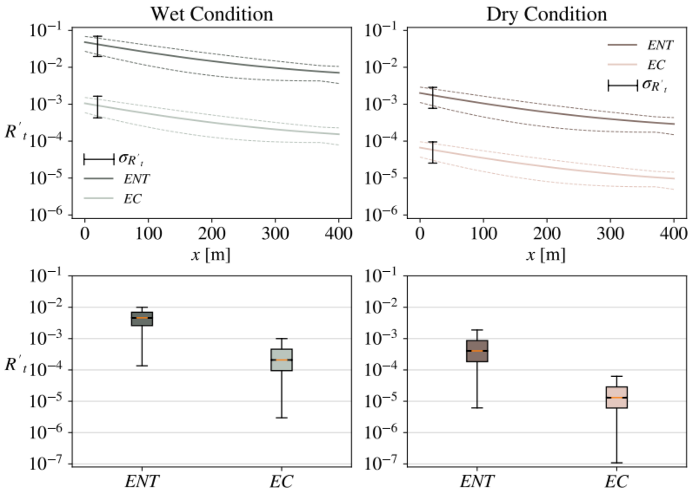

Figure 4: Daily single-user risk of gastrointestinal illness for both Enterococci (ENT) and E. Coli (EC) in case of dry and wet conditions.

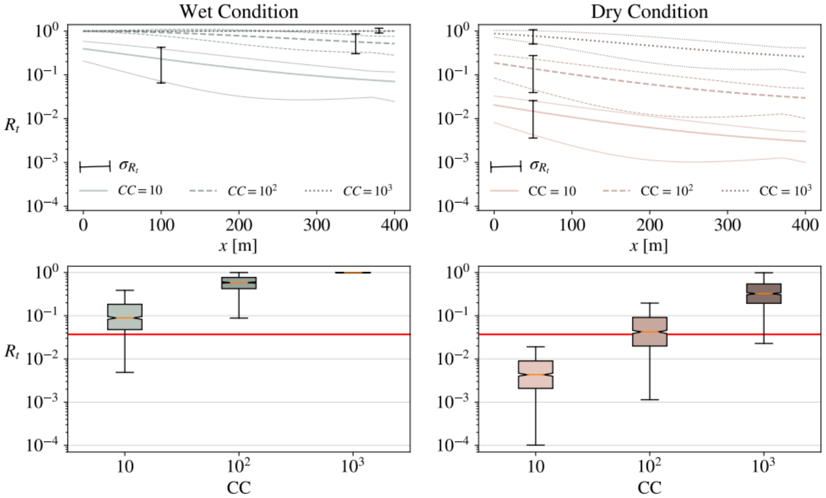

Figure 5: Daily total-users risk R_t for CC individuals swimming in recreational waters near estuary. The red line indicates the acceptable total-users risk R_t*=3.8%

In the upper panels, $R_t(x)$ decreases with the distance from the river mouth and in the lower panels the daily risk R_t is averaged along the longitudinal direction. The impact of weather condition is clear, notice that there is a difference of about two orders of magnitude between wet and dry scenarios. The risk is larger for ENT, which is commonly used as main indicator of gastroenteritis. R_t increases significantly with the number of people swimming in the water. After rain events, the R_t exceeds the acceptable total-users risk (indicated with the red line) even for a small number of beach users, CC=10.

Results

CC as a function of bacterial concentration

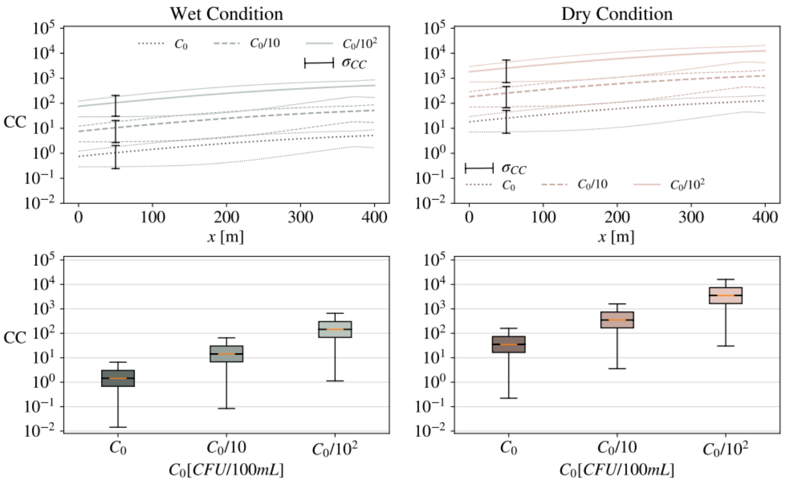

Figure 6: Carrying Capacity CC as a function of the initial concentration C_0

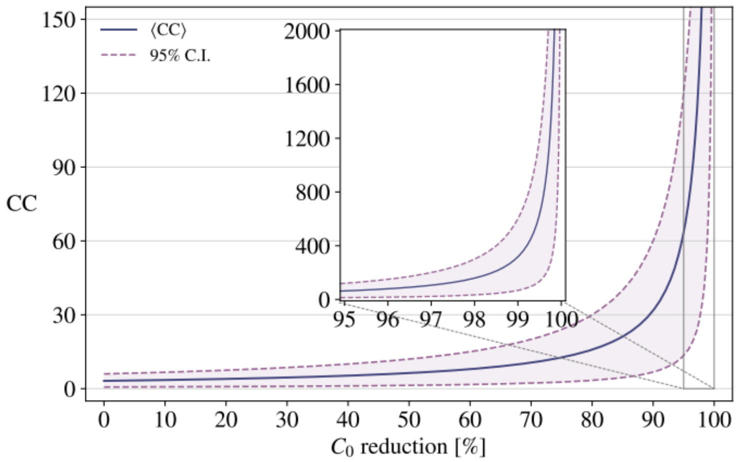

Figure 7: CC as a function of the initial concentration reduction

The Carrying Capacity (CC) is introduced as the number of individuals that can swim in recreational waters with the given acceptable total-users risk R_t*=3.8%. Here C_0 indicates the source concentration of both Enterococci and E. Coli. In particular, a substantial concentration reduction, i.e. C_0/100, would be necessary to obtain a Carrying Capacity larger that 100 users after rain events.

Di Dato et al. (2019)
Our publication

Further details about the methodology and the results can be found in our recently published paper:
Di Dato, M., Galešić, M., Šimundić, P., & Andričević, R. (2019). A novel screening tool for the health risk in recreational waters near estuary: The Carrying Capacity indicator. Science of The Total Environment, 694, 133584.

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A novel screening tool for the health risk in recreational waters near estuary: The Carrying Capacity indicator

Check for updates

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Conclusions

- The present work introduces a simple yet physically-based model to assess the health risk of a recreational marine site, by quantifying the Carrying Capacity, i.e. the number of swimmers that can be safely sustained by a beach resort.
- The method presented here is the result of a combination of two framework: a stochastic framework used to model bacterial transport in estuary and the QMRA to quantify the individual health risk for swimmers.
- Since the sea quality of coastal city is critically impacted by sewage contamination following rainfall event, the weather condition is a key factor when assessing the health status of recreational sites.
- In particular, authorities should address the high level of contamination, especially during storm and post-storm events, by increasing the efficiency of sewage structure (e.g. increase storm-flow storage) and by improving the treatment plants.

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