Development of Regional Joint Master Program in Maritime Environmental Protection and Management
- MEP&M -

LAND and SHIPPING-based effluents as sources of marine pollution: Technologies for its minimization

WP3. Capacity Building through staff training and equipment purchase .
Dev. 3.4.1 KNOW-HOW TRANSFER TO TEACHING STAFF RELATED TO THE MEP&M

Dr. Javier Moreno-Andrés. Dpt. of Environmental Technologies. Marine Research Institute (INMAR)
University of Cádiz.

September - 2021

Virtual meeting via Google-meet application

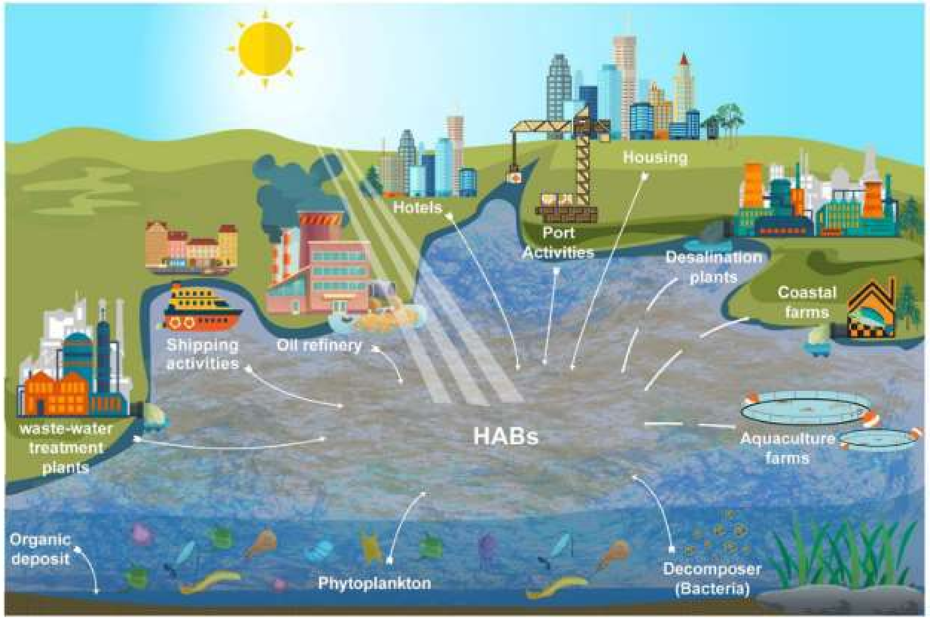
This project has been funded with support from the European Commission. This presentation reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Project no. 619239-EPP-1-2020-1-ME-EPPKA2-CBHE-JP

LAND and SHIPPING-based effluents as sources of marine pollution: Technologies for its minimization.

Co-funded by the Erasmus+ Programme of the European Union

OUTLINE



Trottet, Crit. Rev. Environ. Sci. Technol. 2021, 1–42

Marine Pollution:
A general overview

Land-based effluents

Maritime Transport

17 Goals for People, for Planet

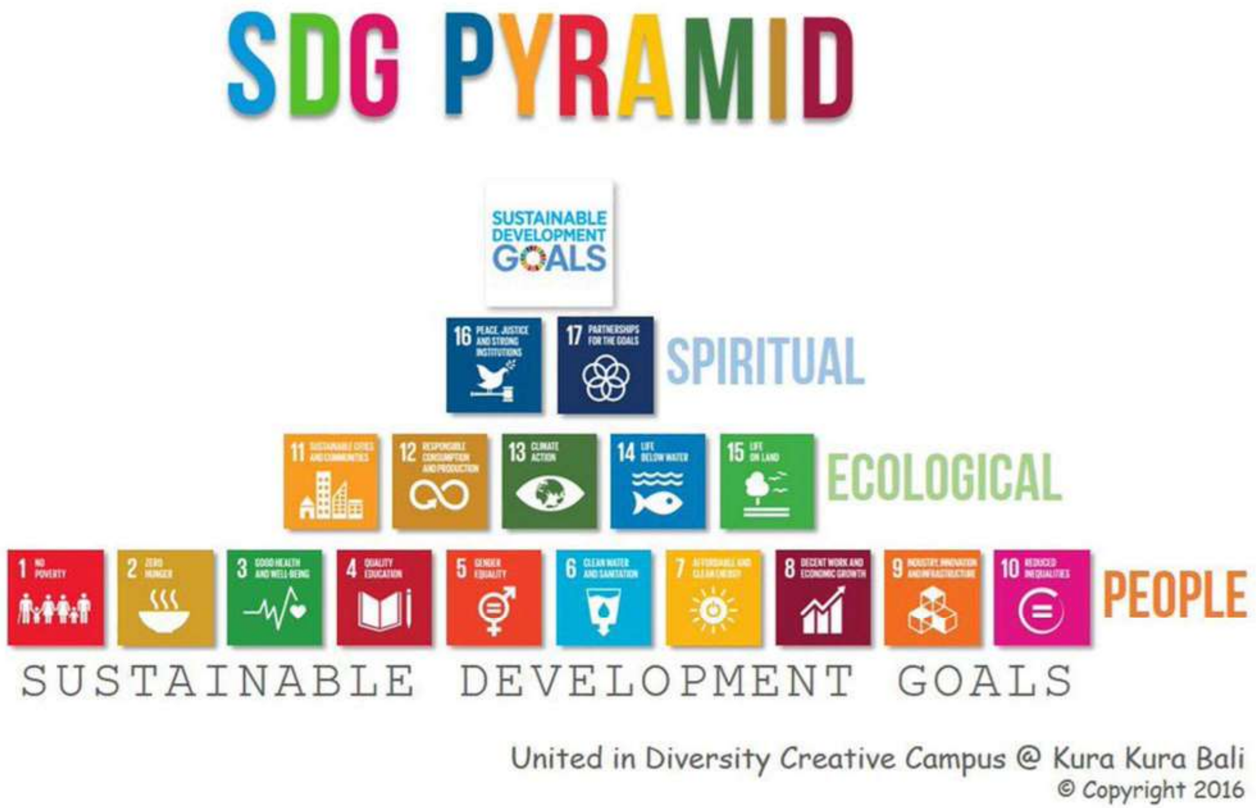
Co-funded by the
Erasmus+ Programme
of the European Union

The Sustainable Development Goals are a universal call to action to end poverty, protect the planet and improve the lives and prospects of everyone, everywhere.

The 17 Goals were adopted by all UN Member States in 2015, as part of the 2030 Agenda for Sustainable Development which set out a 15-year plan to achieve the Goals.

17 Goals for People, for Planet

Co-funded by the Erasmus+ Programme of the European Union



The 17 Goals were adopted by all UN Member States in 2015, as part of the 2030 Agenda for Sustainable Development which set out a 15-year plan to achieve the Goals.

Co-funded by the Erasmus+ Programme of the European Union

6 CLEAN WATER AND SANITATION

6.3 By 2030, improve water quality by **reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater** and substantially **increasing recycling and safe reuse globally**

6.5 By 2030, **implement integrated water resources management** at all levels, including through transboundary cooperation as appropriate

6.6 By 2020, **protect and restore water-related ecosystems**, including mountains, forests, wetlands, rivers, aquifers and lakes

6.A By 2030, **expand international cooperation and capacity-building** support to developing countries in water- and sanitation-related activities and programs, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies

6.B Support and strengthen the **participation of local communities** in improving water and sanitation management

https://sdg6data.org/

SUSTAINABLE DEVELOPMENT GOALS

Conserve and sustainably use the oceans, seas and marine resources for sustainable development

MEP&M UCA Universidad de Cádiz Co-funded by the Erasmus+ Programme of the European Union

14.1 By 2025, **prevent and significantly reduce marine pollution of all kinds**, in particular from land-based activities, including marine debris and nutrient pollution

14.2 By 2020, sustainably **manage and protect marine and coastal ecosystems to avoid significant adverse impacts,** including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans

14.A Increase scientific knowledge, develop research capacity and transfer marine technology, taking into account the Intergovernmental Oceanographic Commission Criteria and Guidelines on the Transfer of Marine Technology, in order to improve ocean health and to enhance the contribution of marine biodiversity to the development of developing countries, in particular small island developing States and least developed countries

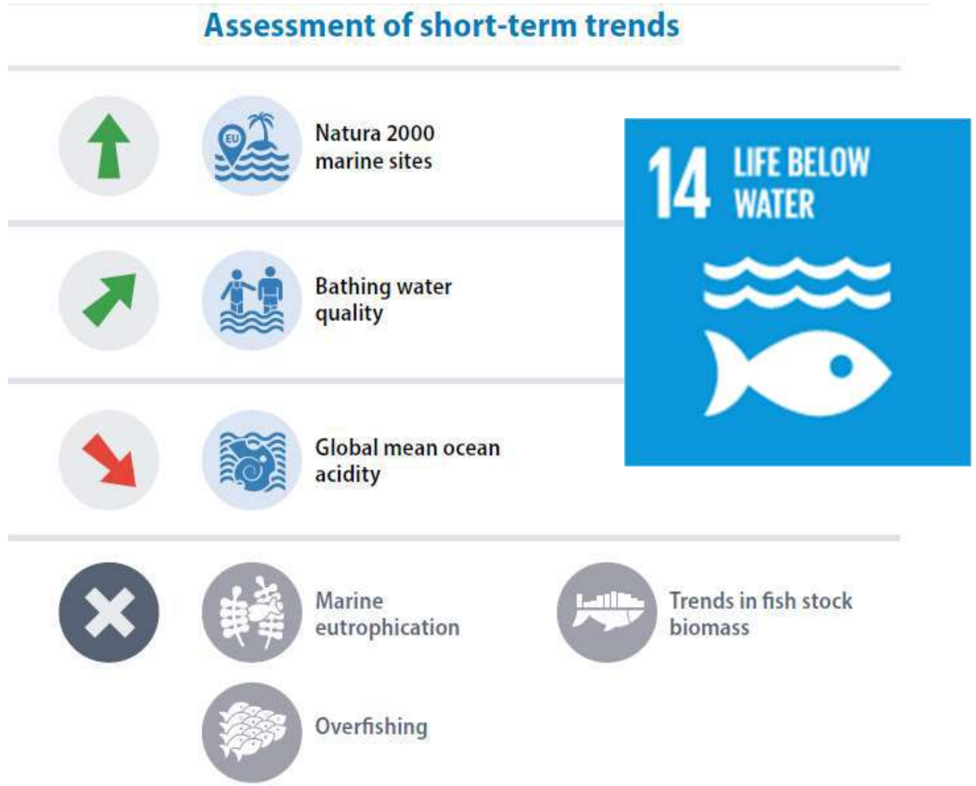
14.C Enhance the conservation and sustainable use of oceans and their resources by implementing international law as reflected in UNCLOS, which provides the legal framework for the conservation and sustainable use of oceans and their resources, as recalled in paragraph 158 of The Future We Want

14 LIFE BELOW WATER

SUSTAINABLE DEVELOPMENT GOALS

Regular monitoring is based on the EU SDG indicator set, developed in cooperation with a large number of partners and stakeholders. The indicator set comprises 100 indicators distributed over the 17 SDGs.

Co-funded by the Erasmus+ Programme of the European Union

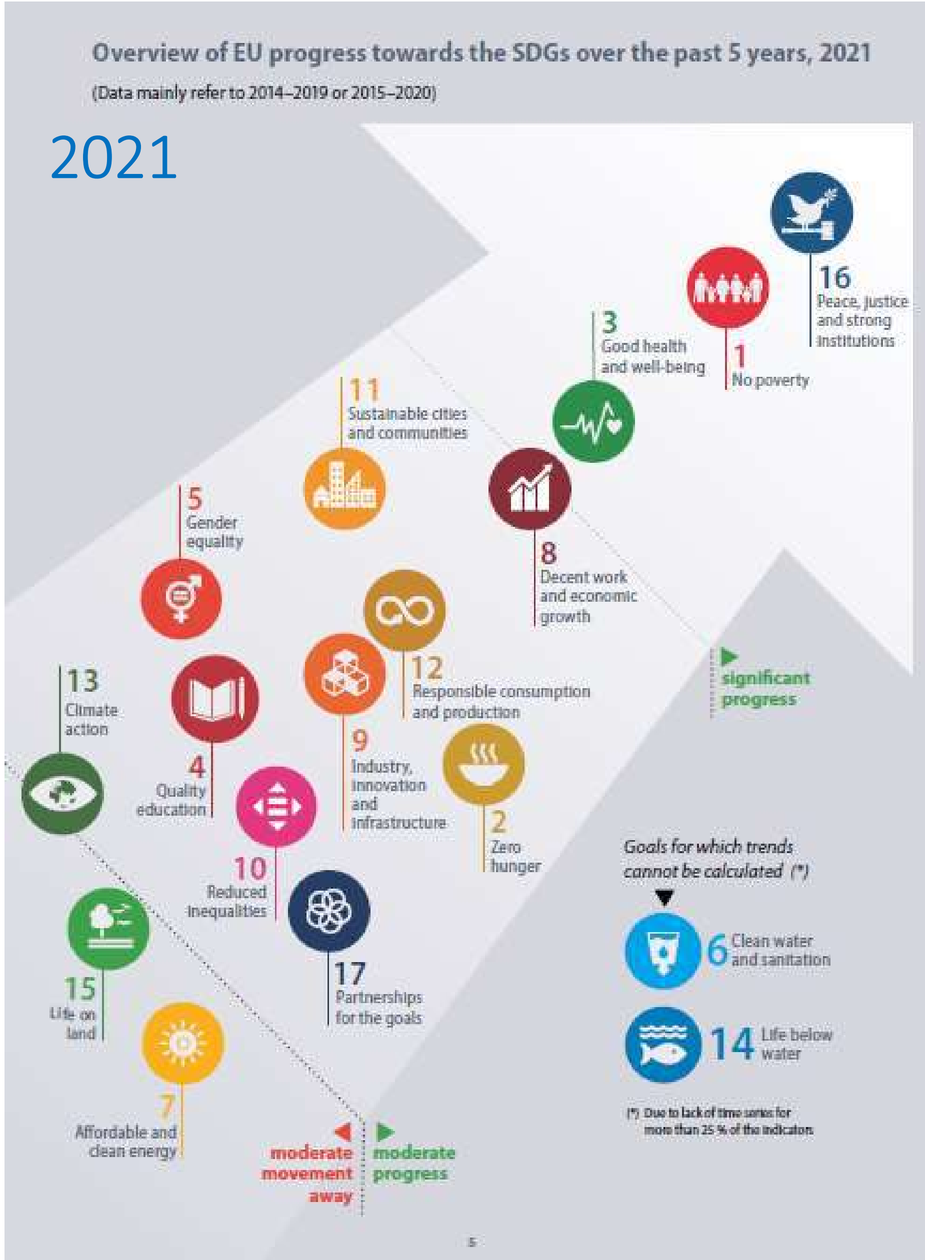


https://ec.europa.eu/eurostat/web/products-eurostat-news/-/wdn-20210615-1
2021
Sustainable development in the European Union Overview of progress towards the SDGs in an EU context. 2021 Edition. Eurostat

Today, progress is being made in many places, but, overall, action to meet the Goals is not yet advancing at the speed or scale required. 2020 needs to usher in a decade of ambitious action to deliver the Goals by 2030.

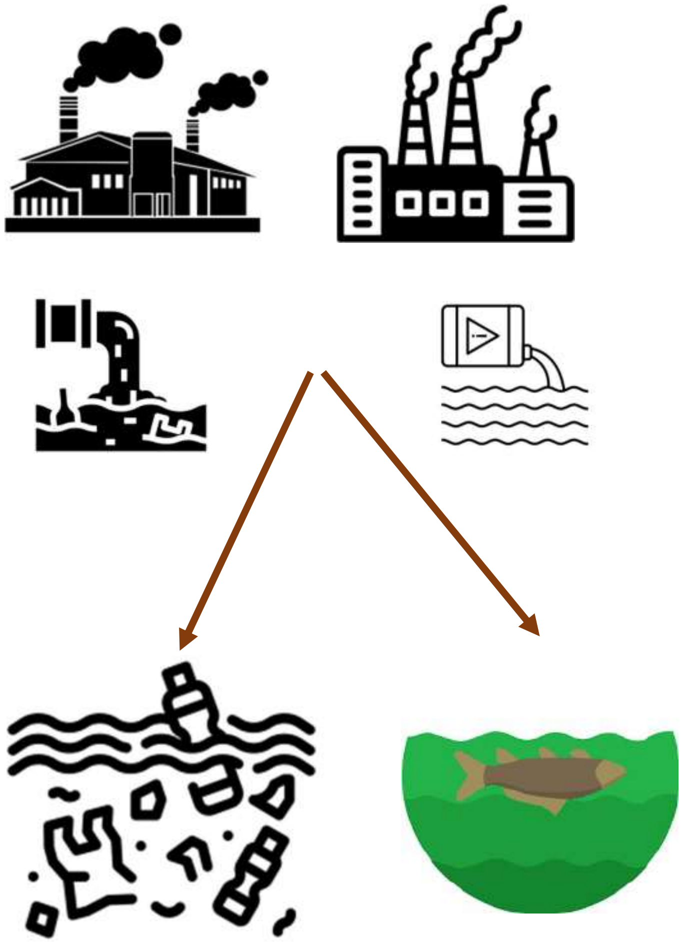
MEP&M


Overview of EU-27 progress towards the SDGs over the past 5 years, 2020
(Data mainly refer to 2013–2018 or 2014–2019)
2020
significant progress
16 Peace, justice and strong institutions
3 Good health and well-being
2 Zero hunger
1 No poverty
4 Quality education
11 Sustainable cities and communities
8 Decent work and economic growth
17 Partnerships for the goals
10 Reduced inequalities
12 Responsible consumption and production
7 Affordable and clean energy
15 Life on land
13 Climate action
9 Industry, innovation and infrastructure
5 Gender equality
moderate movement away
moderate progress
Goals for which trends cannot be calculated (*)
6 Clean water and sanitation
14 Life below water
(*) Due to lack of time series for more than 25 % of the indicators


Overview of EU progress towards the SDGs over the past 5 years, 2021
(Data mainly refer to 2014–2019 or 2015–2020)
2021
16 Peace, justice and strong institutions
1 No poverty
3 Good health and well-being
11 Sustainable cities and communities
5 Gender equality
8 Decent work and economic growth
significant progress
13 Climate action
12 Responsible consumption and production
9 Industry, innovation and infrastructure
4 Quality education
2 Zero hunger
10 Reduced inequalities
15 Life on land
17 Partnerships for the goals
7 Affordable and clean energy
moderate movement away
moderate progress
Goals for which trends cannot be calculated (*)
6 Clean water and sanitation
14 Life below water
(*) Due to lack of time series for more than 25 % of the indicators
5

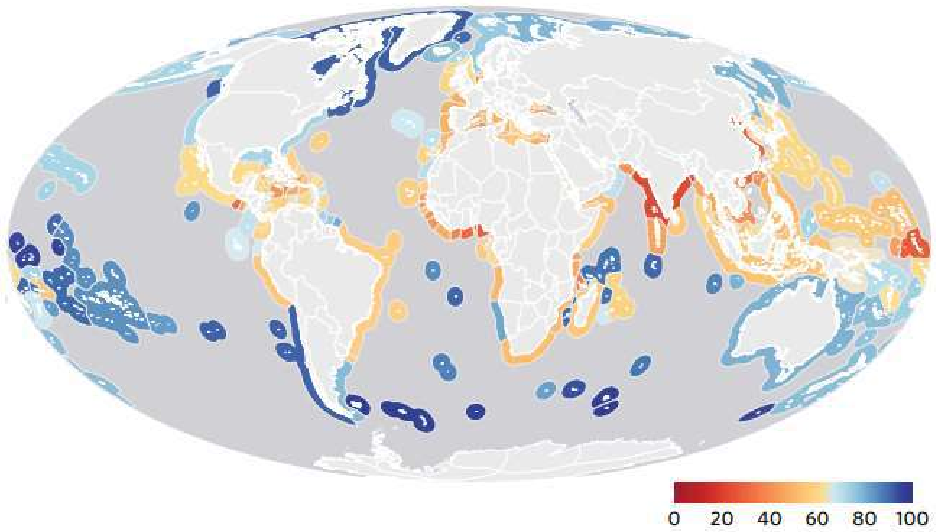
Co-funded by the Erasmus+ Programme of the European Union

Land-based pollutants and marine debris threaten coastal habitats, but **improvements in water quality are achievable**



Clean water indicator

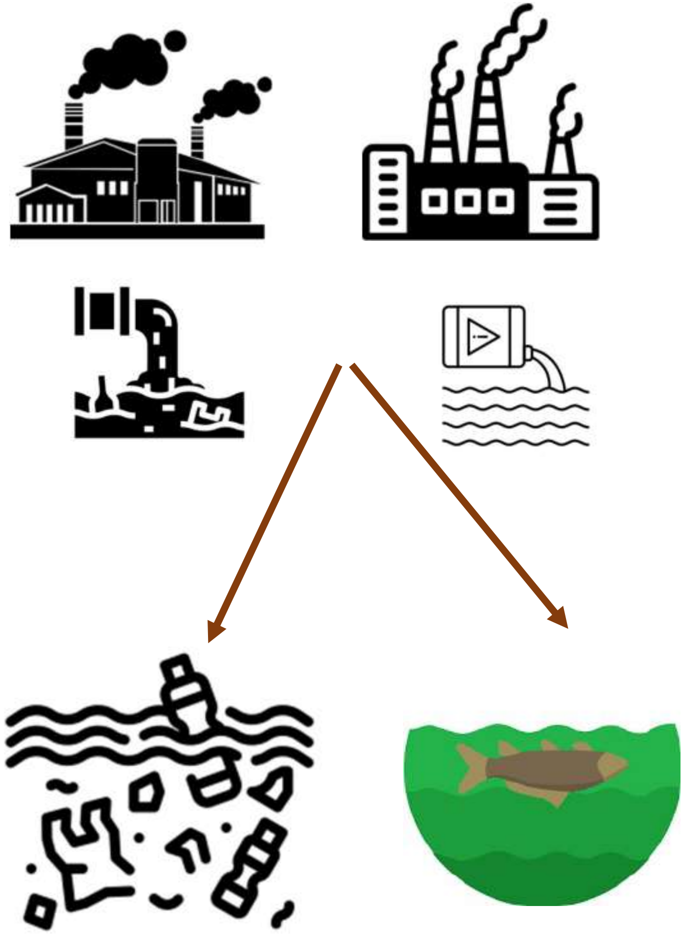
Clean water scores for 220 coastal regions, assessed on a scale of 0 (very polluted) to 100 (clean)

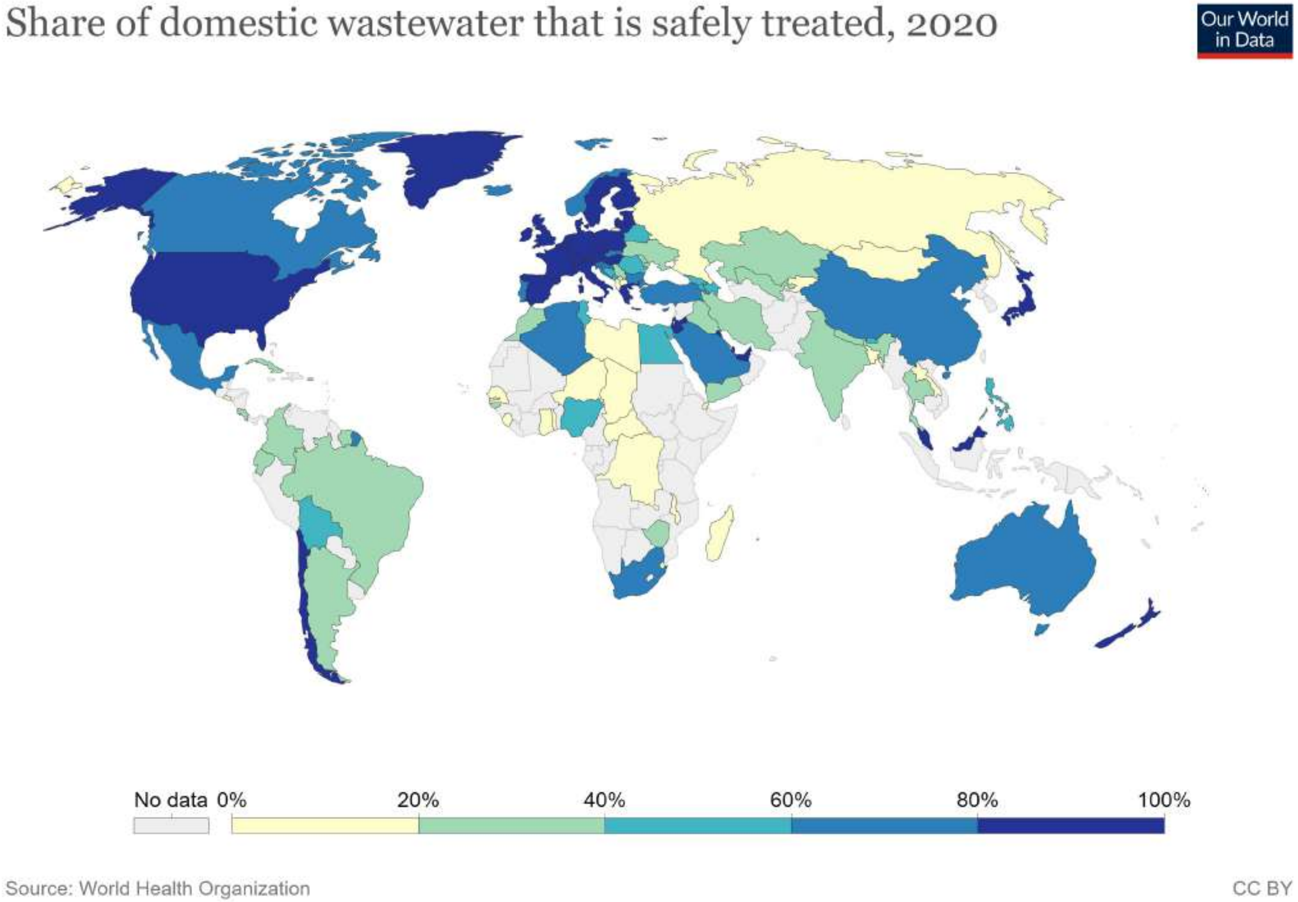


The Sustainable Development Goals Report, 2019

Co-funded by the Erasmus+ Programme of the European Union

Land-based pollutants and marine debris threaten coastal habitats, but **improvements in water quality are achievable**





MEP&M

UCA Universidad de Cádiz

Co-funded by the Erasmus+ Programme of the European Union

"The Science We Need For The Ocean We Want"

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

GLOBAL OCEAN SCIENCE NEEDED TO SUPPORT THE SUSTAINABLE DEVELOPMENT OF OUR SHARED OCEAN.

On 5 December 2017, the United Nations declared that a Decade of Ocean Science for Sustainable Development would be held from 2021 to 2030.

The 2017 Global Ocean Science Report found that **ocean science accounts for only between 0.04% and 4% of total government research** and development expenditures worldwide.

Ocean science can help us to address impacts from climate change, **marine pollution**, ocean acidification, the loss of marine species and degradation of marine and coastal environments.

To achieve sustainable development, good science is needed to inform policies, increase the knowledge of all stakeholders and ultimately deliver solutions to address the decline in ocean health.

The Ocean We Want for a sustainable future is represented by seven Decade Outcomes

- **A clean ocean** where sources of pollution are identified and removed
- **A healthy and resilient ocean** where marine ecosystems are mapped and protected
- **A predicted ocean** where society has the capacity to understand current and future ocean conditions
- **A safe ocean** where people are protected from ocean hazards
- **A sustainably harvested and productive ocean** ensuring the provision of food supply
- **A transparent ocean** with open access to data, information and technologies
- **An inspiring and engaging ocean** where society understands and values the ocean

Key Challenges have been identified for the Decade. Challenges may evolve throughout the Decade and new Challenges will be added. Each Challenge contributes to one or more Decade Outcomes:

1. Understand and beat marine pollution
2. Protect and restore ecosystems and biodiversity
3. Sustainably feed the global population
4. Develop a sustainable and equitable ocean economy
5. Unlock ocean-based solutions to climate change
6. Increase community resilience to ocean hazards
7. Expand the Global Ocean Observing System
8. Create a digital representation of the ocean
9. Deliver data, knowledge and technology to all
10. Change humanity's relationship with the ocean

Co-funded by the Erasmus+ Programme of the European Union

Global Estuaries Monitoring (GEM) Programme

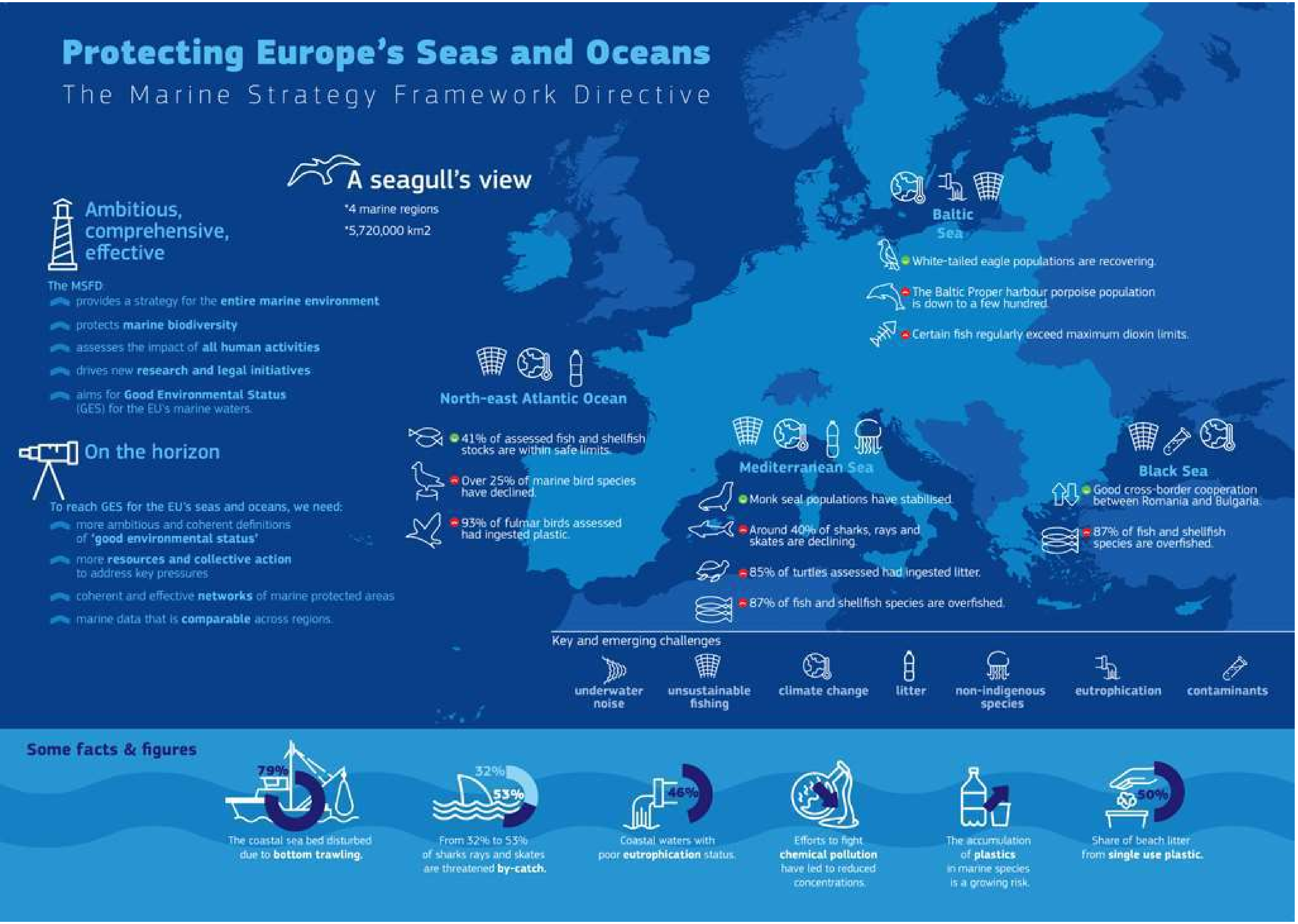
Lead institution(s): State Key Laboratory of Marine Pollution, City University of Hong Kong

- The Global Estuaries Monitoring Programme is co-designed by partners and stakeholders with a view to developing a global monitoring network **to monitor environmental contaminants** (e.g. pharmaceutical residues, emerging pollutants of concern, microplastics, pathogens etc.) **in major urbanised estuaries worldwide**.
- To develop **standard sampling and analysis methods** with provision of training opportunities. This will facilitate capacity building for global estuaries monitoring.
- Results of the Programme will reveal the **pollution situation around the globe**, identify the estuaries that require attention and improvement, **recommend priority contaminants for control**, and promote best practices to combat the pollution problems and thereby achieve cleaner estuaries.

Brest/FRA

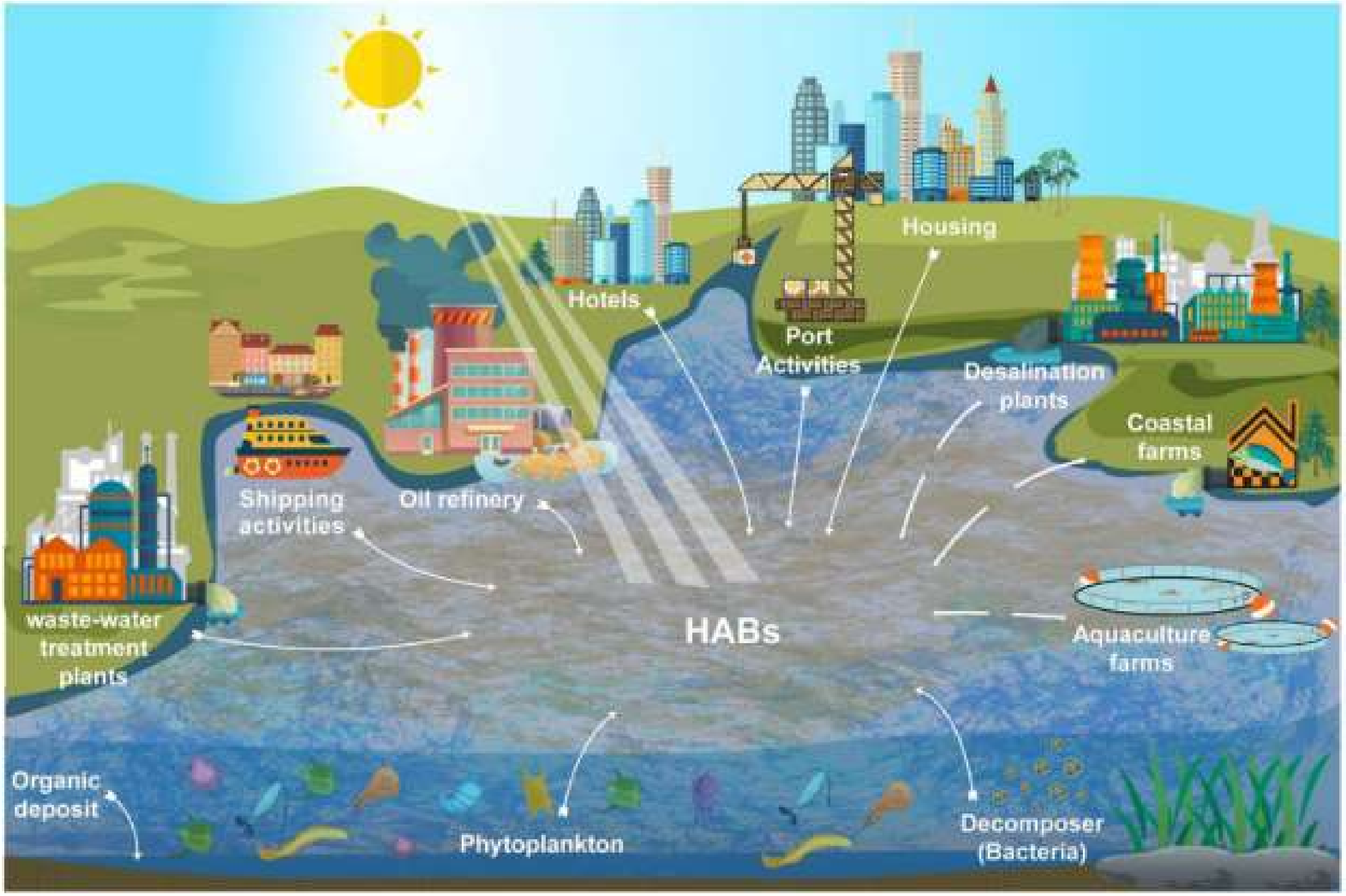
Ocean Hackathon® is 48 hours non-stop to develop a prototype in a team and to think about its use, using various digital data related to the sea.

MSFD



European Commission

Co-funded by the Erasmus+ Programme of the European Union



Trottet, *Crit. Rev. Environ. Sci. Technol.* 2021, 1–42

WASTEWATER

MARITIME TRANSPORT

AQUACULTURE FACILITIES

WASTEWATER

Non-persistent organic & inorganic pollution

- Organic matter in effluents
- Nutrients

Microbial Pollution

Pathogenic microorganisms

Household Chemicals & Contaminants of Emerging Concern

Plastics

Microplastics

Persistent organic xenobiotics

Organochlorine pesticides
Polychlorinated Biphenyl
Polybrominated compounds

Trace metals and organometallic compounds

Beiras, R. Marine Pollution. Elsevier. https://doi.org/10.1016/C2017-0-00260-4

WASTEWATER

MEP&M
UCA Universidad de Cádiz
Co-funded by the Erasmus+ Programme of the European Union

Dissipating pollutants are those that rapidly lose their damaging properties once released into the aquatic environment. Any potential effects are thus only local, and physical dispersion, instantaneous chemical reaction, or rapid biological uptake solves the problem.

- Heat (cooling water from power and nuclear stations)
- Acids and alkalis

Biodegradable pollutants are those susceptible of biological oxidation and eventual mineralization to CO_2, reduced nitrogenous and phosphorus, and water under environmental conditions.

- Natural organic compounds,
- Environmental conditions such as temperature, oxygen availability, and microbial flora may greatly affect degradation rates.

Conventionally, a contaminant is considered as environmentally persistent when its half-life is in the order of months or even years.. According to several American and European regulations,5 a substance is considered as persistent if its half-life in marine water is higher than 60 days, or higher than 180 days in marine sediment.

Persistent or conservative pollutants are those not very chemically reactive and not readily subject to microbial attack either.

- Halogenated hydrocarbons,
- Synthetic polymers,
- Radioactive isotopes
- Trace metals

Beiras, R. Marine Pollution. Elsevier. https://doi.org/10.1016/C2017-0-00260-4

WASTEWATER

Non-persistent organic pollution

MEP&M
UCA Universidad de Cádiz
Co-funded by the Erasmus+ Programme of the European Union

Excess of **organic matter** in water causes oxygen depletion

Biodegradable organic matter → Biological Oxygen Demand (BOD)

Non-biodegradable organic matter → Chemical Oxygen Demand (COD)

Suspended Solids

· Hypoxia, (D.O. <2 mg/L),

· Anoxia, DO values are near zero (<0.1 mg/L).

Urban wastewaters: Biodegradable

BOD_5/COD factor →
- > 0.4 mg/L Biodegradable
- 0.2-.04 mg/L Low biodogradable
- ≤ 0.2 mg/L No Biodegradable

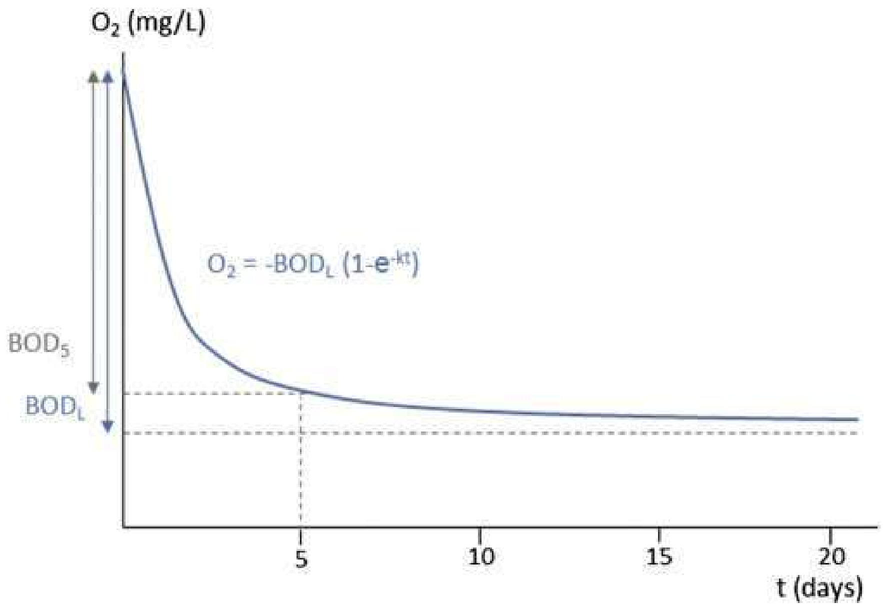
Every person contributes with a load of c. 70 g BOD/day to the organic matter disposed as liquid wastes through the domestic sewage.

Beiras, R. Marine Pollution. Elsevier.
https://doi.org/10.1016/C2017-0-00260-4

WASTEWATER

Non-persistent organic pollution

Co-funded by the Erasmus+ Programme of the European Union



Water	**BOD_5 (mg/L)**
Clean natural waters	<3
Run-off water	10–15
Untreated municipal wastewater	200–400
Paper mill wastewaters	300–700
Meat processing raw effluent	500–1500
Dairy processing raw effluent	2500
Bakery processing raw effluent	2000–4000
Treated urban effluents	<25 Directive 91/271/EEC

Beiras, R. Marine Pollution. Elsevier.
https://doi.org/10.1016/C2017-0-00260-4

MEP&M UCA Universidad de Cádiz Co-funded by the Erasmus+ Programme of the European Union

Table 1 : Requirements for discharges from urban waste water treatment plants subject to Articles 4 and 5 of the Directive. The values for concentration or for the percentage of reduction shall apply.

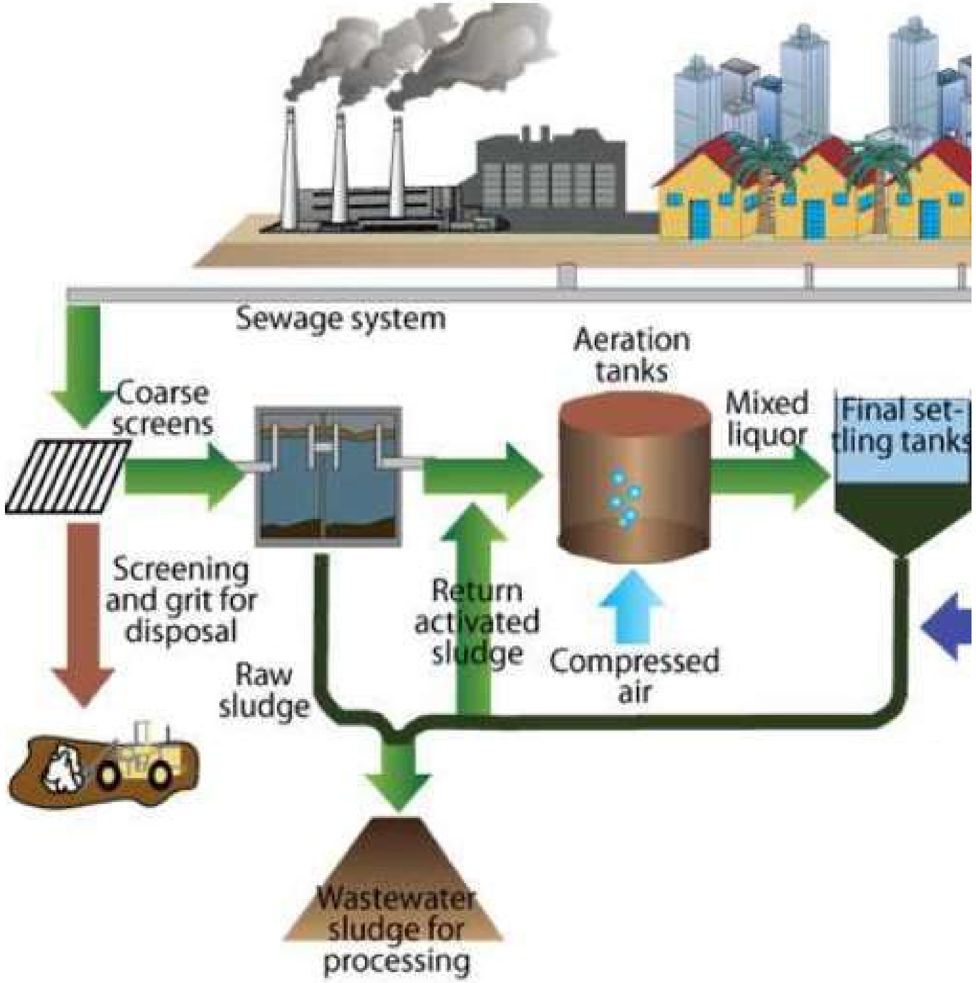
Parameters	Concentration	Minimum percentage of reduction (1)	Reference method of measurement
Biochemical oxygen demand (BOD5 at 20 °C) without nitrification (2)	25 mg/l O_2	70-90 40 under Article 4 (2)	Homogenized, unfiltered, undecanted sample. Determination of dissolved oxygen before and after five-day incubation at 20 °C ± 1 °C, in complete darkness. Addition of a nitrification inhibitor
Chemical oxygen demand (COD)	125 mg/l O_2	75	Homogenized, unfiltered, undecanted sample Potassium dichromate
Total suspended solids	35 mg/l (3) 35 under Article 4 (2) (more than 10 000 p.e.) 60 under Article 4 (2) (2 000-10 000 p.e.)	90 (3) 90 under Article 4 (2) (more than 10 000 p.e.) 70 under Article 4 (2) (2 000-10 000 p.e.)	— Filtering of a representative sample through a 0,45 μm filter membrane. Drying at 105 °C and weighing — Centrifuging of a representative sample (for at least five mins with mean acceleration of 2 800 to 3 200 g), drying at 105 °C and weighing

(1) Reduction in relation to the load of the influent.
(2) The parameter can be replaced by another parameter : total organic carbon (TOC) or total oxygen demand (TOD) if a relationship can be established between BOD5 and the substitute parameter.
(3) This requirement is optional.

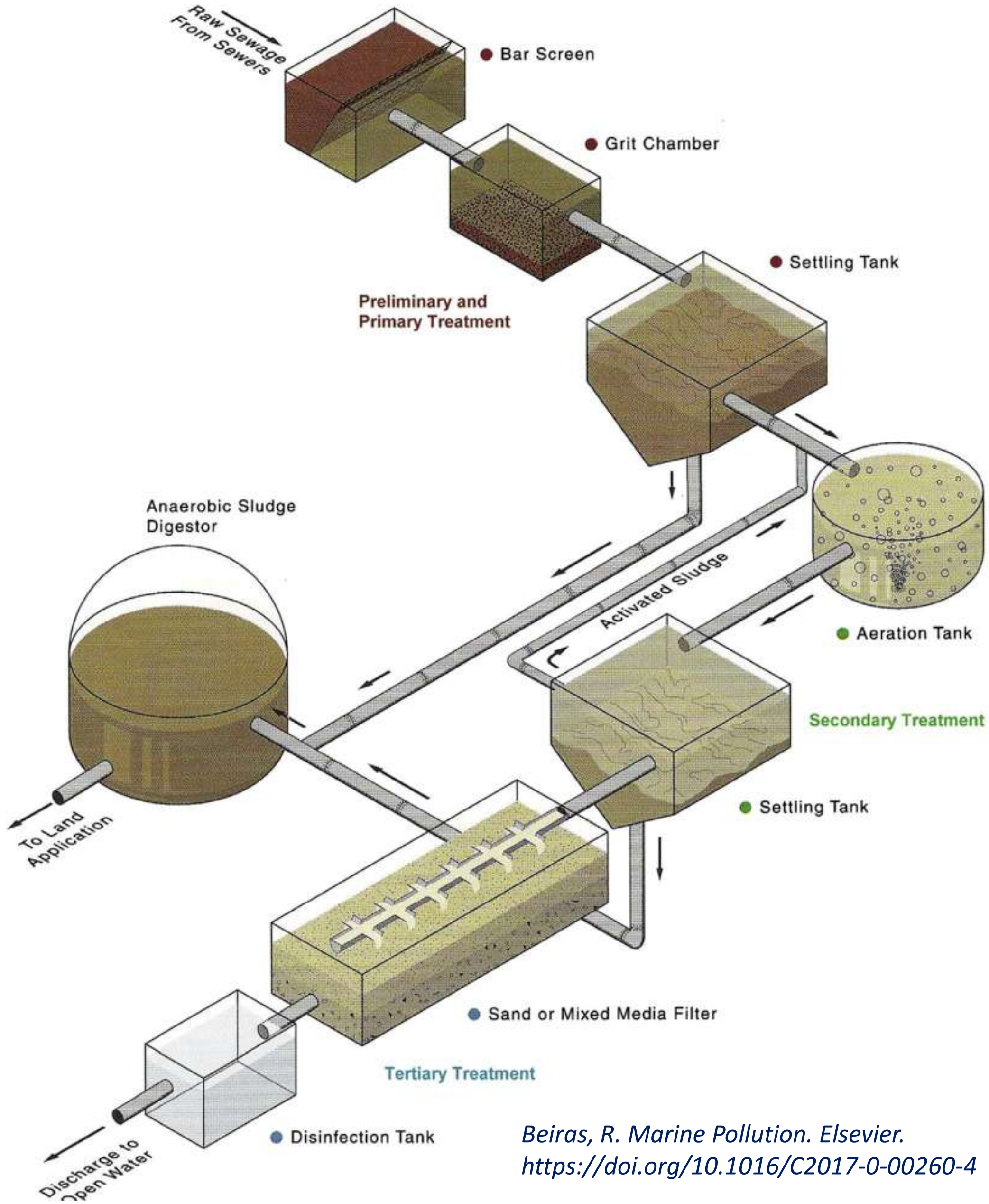
Directive 91/271/EEC

WASTEWATER

Non-persistent organic pollution

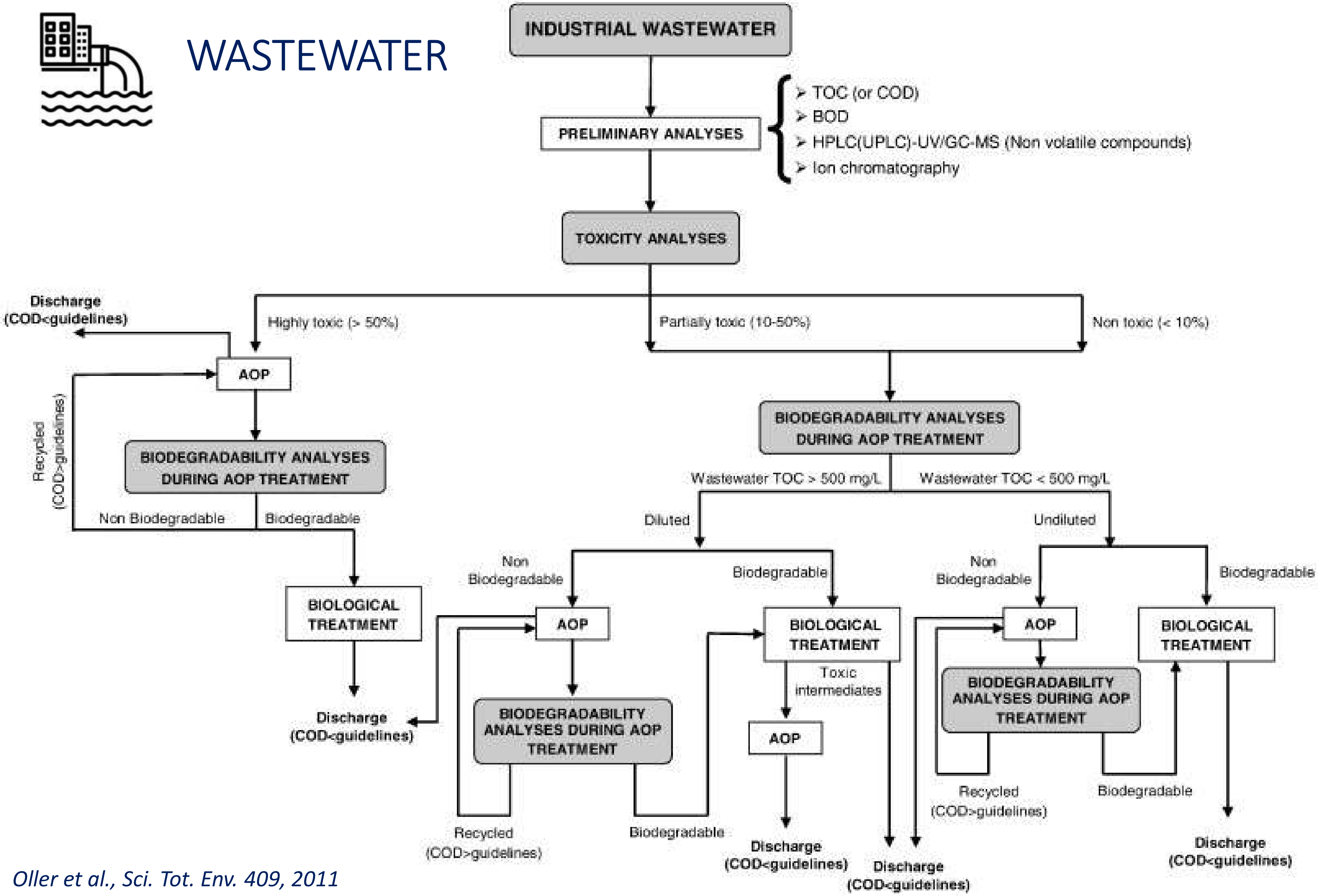


Kruczynski WL and Fletcher PJ. 2012.



Beiras, R. Marine Pollution. Elsevier. https://doi.org/10.1016/C2017-0-00260-4

WASTEWATER



Oller et al., Sci. Tot. Env. 409, 2011

ed by the
gramme
an Union

Industrial wastewaters

Low Biodegradable

MAIN GOAL:
ADVANCED TREATMENTS
OR
INCREASE BIODEGRADABILITY TO REACH A REGULAR WWTP

WASTEWATER

Non-persistent inorganic pollution

MEP&M UCA Universidad de Cádiz
Co-funded by the Erasmus+ Programme of the European Union

Anthropogenic inputs of **nutrients** may lead to (hyper) eutrophication

Hypoxia, (D.O. <2 mg/L),

Anoxia, DO values are near zero (<0.1 mg/L).

The main anthropogenic sources of N and P are fertilizers and detergents

This can be avoided by eliminating P from the wastewaters through specific tertiary treatments. The application of this treatment to wastewater was successful in reducing P loads in some coastal environments.

P pollution was more effectively abated than N pollution

The tertiary treatment of urban wastewater succeeded in reducing the loads of P in many polluted water bodies, while the progress against N hypereutrophication is more limited.

Treated urban wastewater should have **below 2 mg/L P and below 15 mg/L N.**

Beiras, R. Marine Pollution. Elsevier. https://doi.org/10.1016/C2017-0-00260-4

Co-funded by the Erasmus+ Programme of the European Union

Table 2: Requirements for discharges from urban waste water treatment plants to sensitive areas which are subject to eutrophication as identified in Annex II.A (a). One or both parameters may be applied depending on the local situation. The values for concentration or for the percentage of reduction shall apply.

Parameters	Concentration	Minimum percentage of reduction (1)	Reference method of measurement
Total phosphorus	2 mg/l P (10 000 - 100 000 p. e.) 1 mg/l P (more than 100 000 p. e.)	80	Molecular absorption spectrophotometry
Total nitrogen (2)	15 mg/l N (10 000 - 100 000 p. e.) 10 mg/l N (more than 100 000 p. e.) (3)	70-80	Molecular absorption spectrophotometry

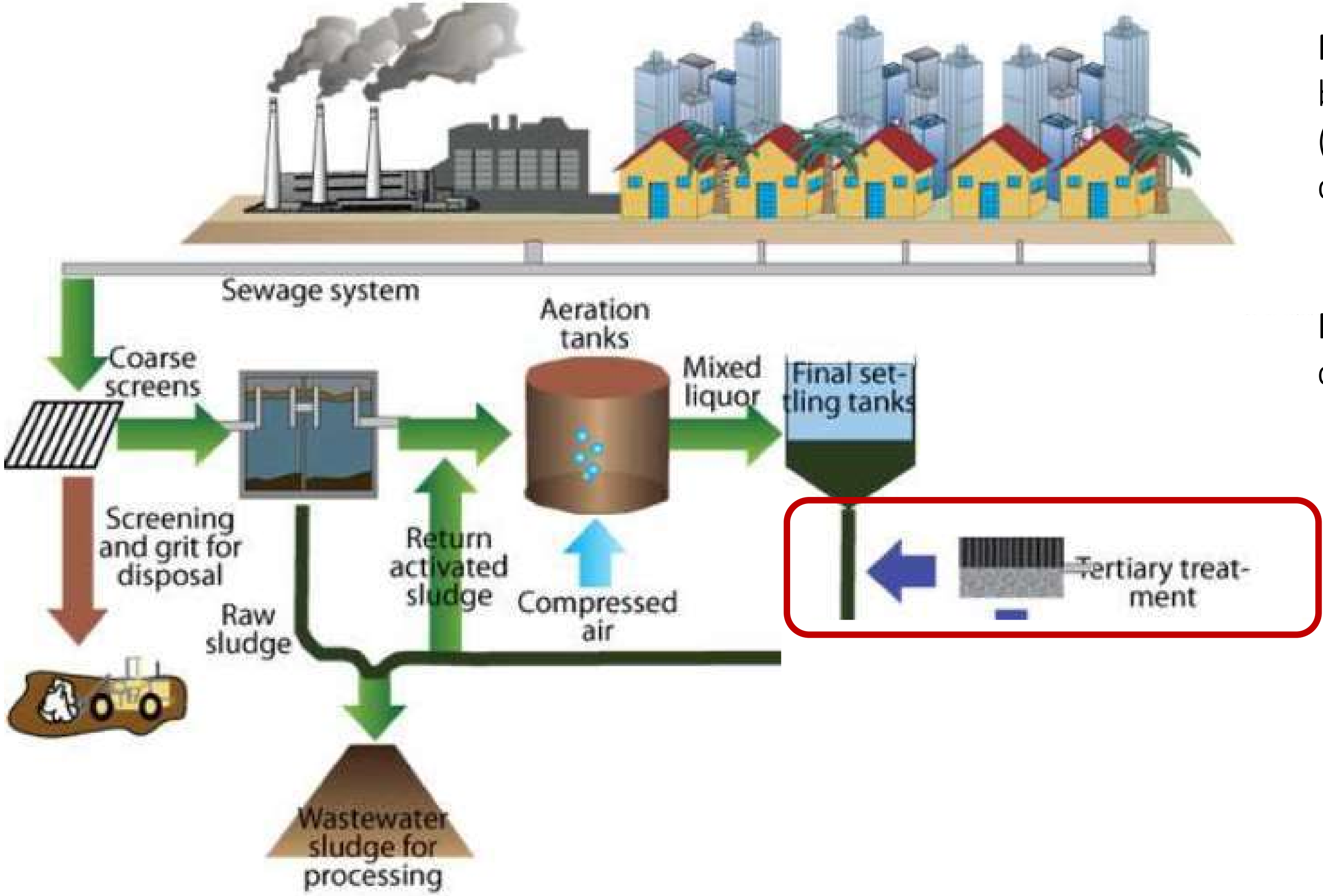
(1) Reduction in relation to the load of the influent.
(2) Total nitrogen means: the sum of total Kjeldahl-nitrogen (organic N + NH_3), nitrate (NO_3)-nitrogen and nitrite (NO_2)-nitrogen.
(3) Alternatively, the daily average must not exceed 20 mg/l N. This requirement refers to a water temperature of 12° C or more during the operation of the biological reactor of the waste water treatment plant. As a substitute for the condition concerning the temperature, it is possible to apply a limited time of operation, which takes into account the regional climatic conditions. This alternative applies if it can be shown that paragraph 1 of Annex I.D is fulfilled.

Directive 91/271/EEC

WASTEWATER

Non-persistent inorganic pollution

Co-funded by the Erasmus+ Programme of the European Union



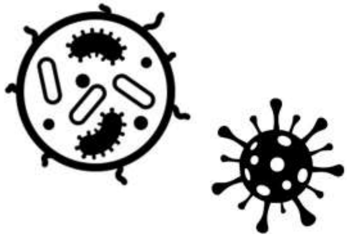
Kruczynski WL and Fletcher PJ. 2012.

N removal can be achieved by bacterial nitrification (aerobic) plus denitrification (anaerobic)

P removal is achieved by chemical coagulation

WASTEWATER

Microbial pollution



MEP&M · UCA Universidad de Cádiz · Co-funded by the Erasmus+ Programme of the European Union

Contamination of natural waters by human sewage, including urine and feces of people suffering from infectious diseases, poses a risk to public health.

Waterborne diseases

The most abundant enteric bacteria, *E. coli*, is universally used as indicator of fecal contamination:

· **Nonpathogenic symbiotic species** with a similar or even higher resistance to environmental conditions than disease-causing bacteria,

· Its **absence from water** is an indication that water is **bacteriologically safe**.

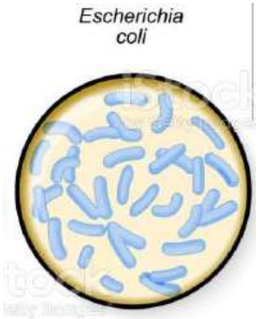
· **Nonexistent as free-living form**, is **indicative of fecal contamination** and thus potential presence of any of the other enteric organisms capable of causing disease.

Beiras, R. Marine Pollution. Elsevier.
https://doi.org/10.1016/C2017-0-00260-4

Each person liberates 300,000 million *E. coli* daily.

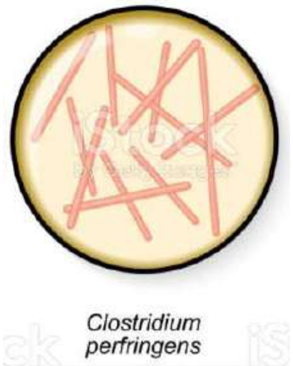
Co-funded by the Erasmus+ Programme of the European Union

BACTERIAL INDICATORS



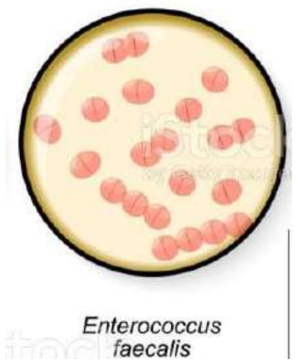
The use of *E. coli* as a single universal indicator has limitations.

… their environmental resistance is much lower than that of other important pathogens such as protozoans and viruses.

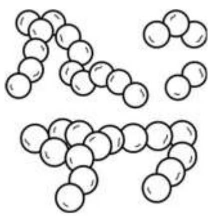


Clostridium perfringens, a spore-forming anaerobic bacteria with longer survival times in the marine waters.
Coliphages and *C. perfringens* have lower decay rates than fecal coliforms… so may they are better indicators of remote fecal sources.

Spore-forming bacteria, protozoans, and viruses are more persistent than *E. coli* in natural waters



Enterococci are a more accurate indicator than coliforms because they are more closely associated with human rather than with animal fecal matter and **survive longer in aquatic environments**.



Beiras, R. Marine Pollution. Elsevier. https://doi.org/10.1016/C2017-0-00260-4

DIRECTIVE 2006/7/EC

For coastal waters and transitional waters

	A	B	C	D	E
	Parameter	Excellent quality	Good quality	Sufficient	Reference methods of analysis
1	Intestinal enterococci (cfu/100 ml)	100 (*)	200 (*)	185 (**)	ISO 7899-1 or ISO 7899-2
2	Escherichia coli (cfu/100 ml)	250 (*)	500 (*)	500 (**)	ISO 9308-3 or ISO 9308-1

(*) Based upon a 95-percentile evaluation. See Annex II.
(**) Based upon a 90-percentile evaluation. See Annex II.

REGULATION (EU) 2020/741

Table 2 – Reclaimed water quality requirements for agricultural irrigation

Reclaimed water quality class	Indicative technology target	Quality requirements				
		E. coli (number/100 ml)	BOD_5 (mg/l)	TSS (mg/l)	Turbidity (NTU)	Other
A	Secondary treatment, filtration, and disinfection	≤ 10	≤ 10	≤ 10	≤ 5	*Legionella* spp.: < 1 000 cfu/l where there is a risk of aerosolisation Intestinal nematodes (helminth eggs): ≤ 1 egg/l for irrigation of pastures or forage
B	Secondary treatment, and disinfection	≤ 100	In accordance with Directive 91/271/EEC (Annex I, Table 1)	In accordance with Directive 91/271/EEC (Annex I, Table 1)	-	
C	Secondary treatment, and disinfection	≤ 1 000			-	
D	Secondary treatment, and disinfection	≤ 10 000			-	

WASTEWATER

Microbial pollution

MEP&M
UCA Universidad de Cádiz
Co-funded by the Erasmus+ Programme of the European Union

The disappearance of fecal microorganisms in seawater is primarily due to a **dilution process** together with the physical, chemical and biological factors.

Mortality curves for bacteria in natural waters follow first-order kinetics.

T90, a parameter corresponding to the time required for a 90% reduction in number of the effluent's fecal microbiota.

$$dN/dt = -k \cdot N \rightarrow N_t = N_0 \cdot e^{-kt}$$

- $-k$: Extinction rate of microorganisms
- N: Concentration of microorganisms at certain time (Nt) or at initial conditions (N0)

$$\ln N_t / \ln N_0 = -k \cdot t$$

$$\ln (100/10) / k = T90$$

- $(100/10)$: When 90% of the death is achieved, Nt/N0 = 0.1. $N_0 = 100$; $N_t = 10$

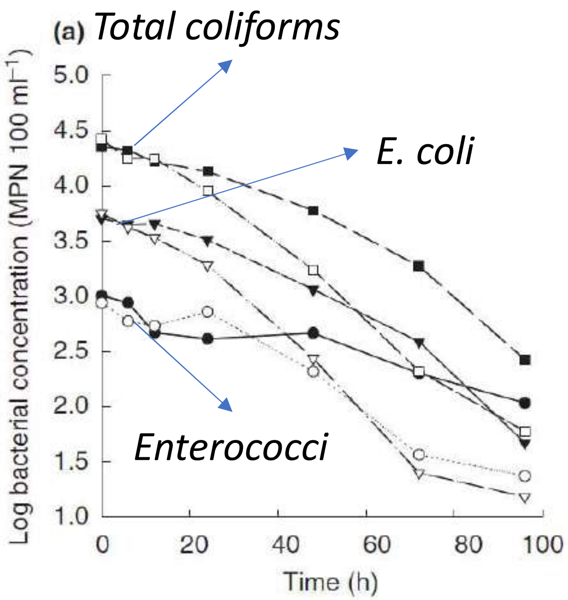
Beiras, R. Marine Pollution. Elsevier. https://doi.org/10.1016/C2017-0-00260-4
Nebot, E. Ecuaciones y Cálculos para el tratamietno de aguas. Paraninfo.

Bathing Water Profiles, Best Practices and Guidance" (2009), published by the European Union (EU), recognizes that the elimination of bacteria in seawater depends on the hours of sunshine and temperature

Table 5. Time elimination of 90% of the population of bacteria in the seawater depending on temperature (Bathing Water Committee, 2009).

	Sunny		Cloudy	
T.90 (hours)	20 °C	5 °C	20 °C	5 °C
E. coli	5 h	50 h	35 h	35 h
Enterococci	15 h	100 h	70 h	300 h

Aragonés, et al. 2016. Science of the Total Environment. 566, 288-297.



Indicator bacteria	k_D (S.E./n) (at 20°C)	T90 (h) (at 20°C)	k_D (S.E./n) (at 14°C)	T90 (h) (at 14°C)
Total coliforms	0·027 (0·0011/12)	85·2	0·019 (0·0009/12)	121·2
Escherichia coli	0·029 (0·0006/12)	79·4	0·021 (0·0010/12)	109·7
Enterococci	0·020 (0·0014/12)	115·1	0·013 (0·0017/12)	177·1

S.E., standard error; n, sample size.

Noble et al. 2004. Journal of Applied Microbiology 2004, 96, 464–472

WASTEWATER

Microbial pollution

Co-funded by the Erasmus+ Programme of the European Union

Beiras, R. Marine Pollution. Elsevier. https://doi.org/10.1016/C2017-0-00260-4

SHELLFISH: risk of bacterial accumulation

Molluskan shellfish safety is assured through microbiological tests compulsory prior to placing the shellfish in the market

Bivalve producing areas are classified according to their microbiological quality

Class A are areas from which live bivalve mollusks may be collected for direct human consumption because they meet the microbiological criteria (EC 2073/2005)

Class B are areas from which bivalves can be collected but need purification prior to be placed on the market.

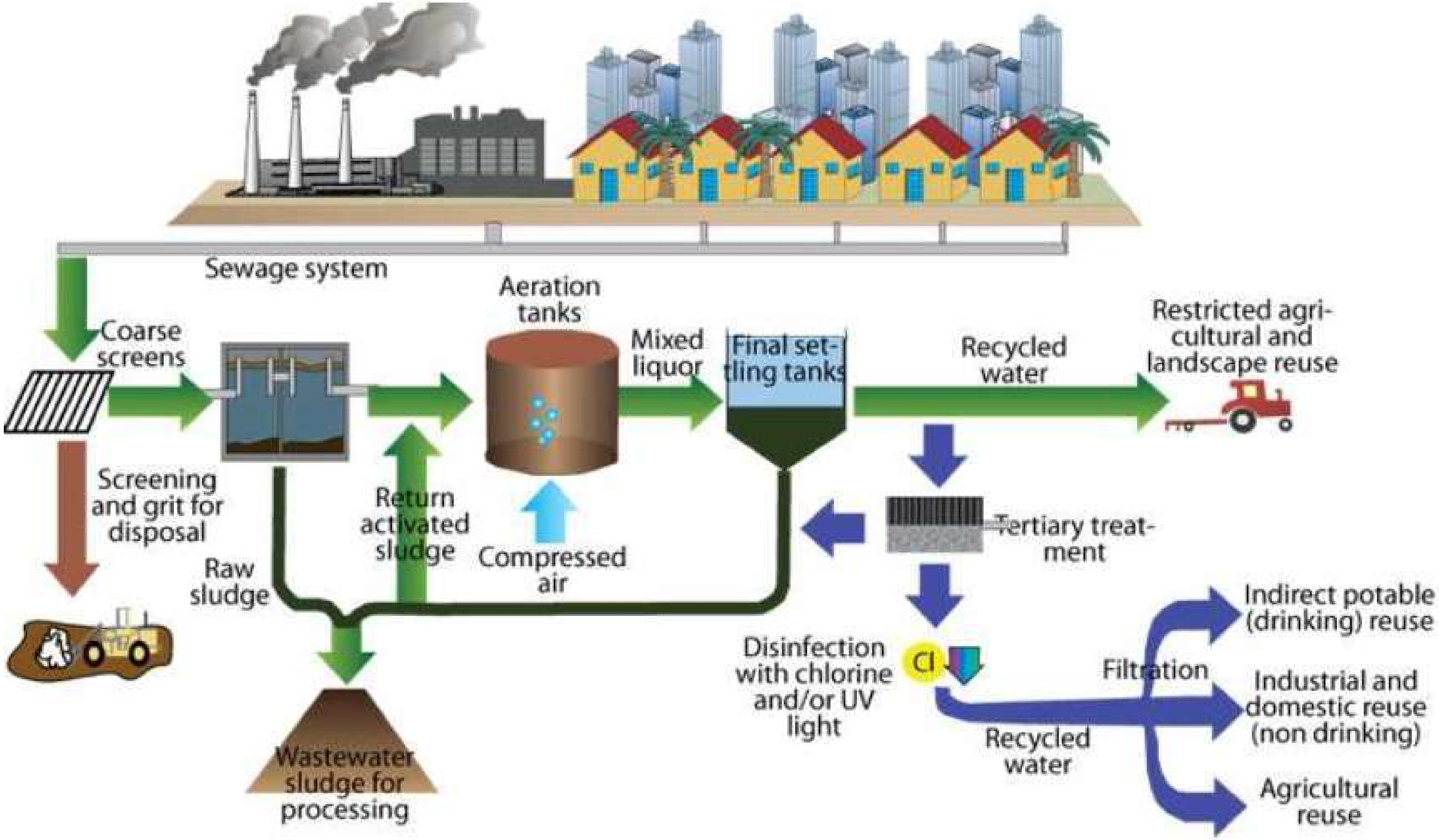
Class C are areas from which bivalves can be collected but placed on the market only after relying over a long period so as to meet Class A requirements.

Classification of Shellfish Growing Areas According to Their Microbiological Quality in Europe
(**Regulations EC 854/2004 and EC2073/2005**)

EU Regulations	"Class A"	"Class B"	"Class C"
Controls in shellfish meat	≤230 *E. coli* MPN in 100 g Absence of Salmonella in 25 g	≤4,600 *E. coli* per 100 g	≤46,000 *E. coli* per 100 g

WASTEWATER

Co-funded by the Erasmus+ Programme of the European Union



Kruczynski WL and Fletcher PJ. 2012.

Co-funded by the Erasmus+ Programme of the European Union

Table 5.1 Summary of the Main Advantages and Limitations of the Disinfection Methods Suitable for Application to Wastewater

Disinfectant	Advantages	Limitations
Cl_2	Cost-effective	Production of halomethanes and other by-side toxic products
ClO_2	Produces less halomethanes	More costly than Cl_2
O_3	Very effective against viruses and protozoans cysts, does not produce halomethanes	Costly; demands in situ production
UV	Does not produce halomethanes	Costly because of electricity consumption; suitable for low fluxes only due to limited penetration in water

Table 5.2 Germicidal Efficiency of Different Disinfectants Applied to Wastewater

	$C_R \cdot t$ (mg min/L) for 99.9 percent Inactivation (pH = 7; T = 20°C)		
Disinfectant	Bacteria	Virus	Protozoan Cysts
Cl_2	1.5–3	4–5	70–80
ClO_2	20–30	6–12	20–25
O_3	–	0.5–0.9	0.7–1.4
UV	60–80	50–60	15–25

Own elaboration. Data from Metcalf & Eddy, Inc. Wastewater engineering. Treatment and reuse. 4th ed. McGrawhill; 2004.

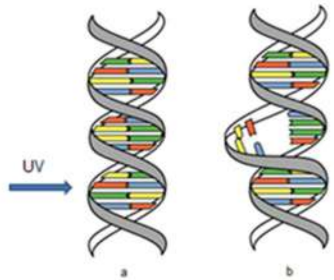
Beiras, R. Marine Pollution. Elsevier.
https://doi.org/10.1016/C2017-0-00260-4

WASTEWATER
Microbial pollution

Co-funded by the Erasmus+ Programme of the European Union

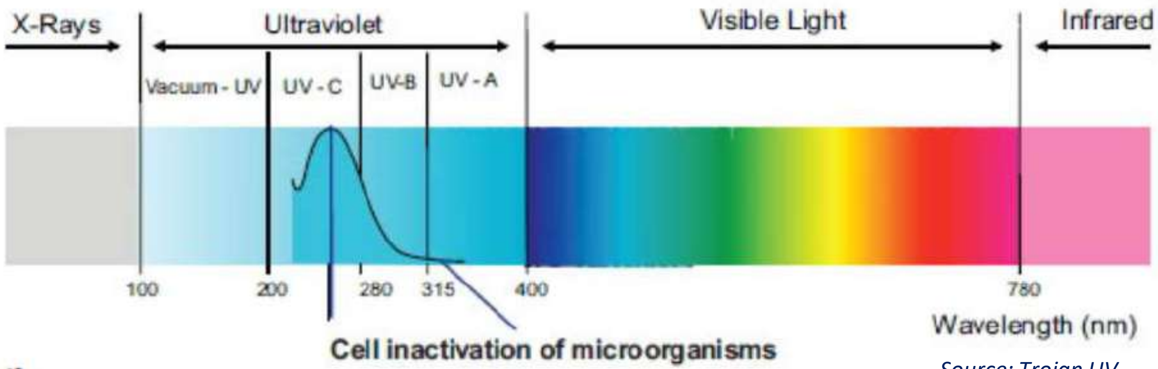
DISINFECTION TECHNOLOGY

UV-light "can be considered as a traceless and green reagent"
Su et al. (2014)



UV-radiation

UV light is transferred to genetic material.
Inhibit normal DNA replication and therefore lead to the inactivation of microorganisms



Source: Trojan UV

UV-C most germicidal wavelength, with DNA damage

UV-B oxidative stress and DNA damage

UV-A oxidative damage to lipids and proteins

The most effective spectral region for inactivation occurs at a wavelength of 254 nm (UV-C), since DNA exposed to this energy has a maximum absorption, and therefore inactivation

MAIN ADVANTAGE: not generates by- products

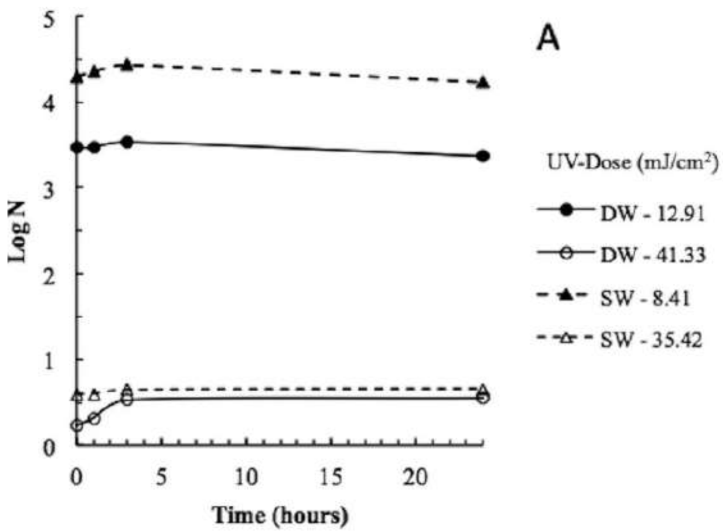
Hijnen, E.F. et al. (2006)
Nebot, E. et al. (2007)
Santos, et al. 2013, 195, 63–74, doi:10.1007/s00203-012-0847-5.

WASTEWATER
Microbial pollution

Co-funded by the Erasmus+ Programme of the European Union

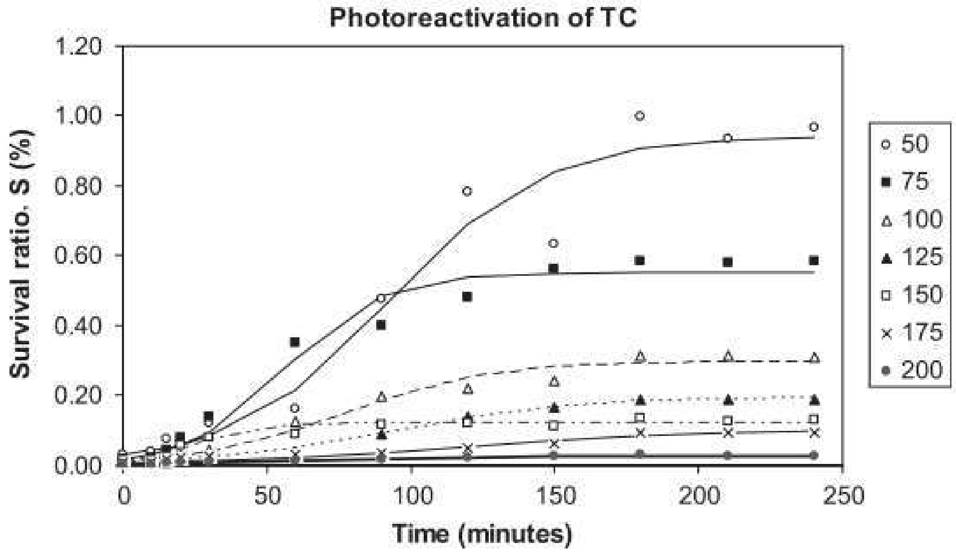
Published studies indicate that **percent repair** does not exceed 4%.

Dark repair: Enterococcus faecalis



Moreno-Andrés, et al., 2016. Chem. Eng. J. 283, 1339–1348.

E. coli



*Nebot et al., Water Res., 2007, **41**, 3141–3151.*

A few studies examining heterotrophic bacteria and indicated regrowth within hours to days after a successful disinfection treatment…

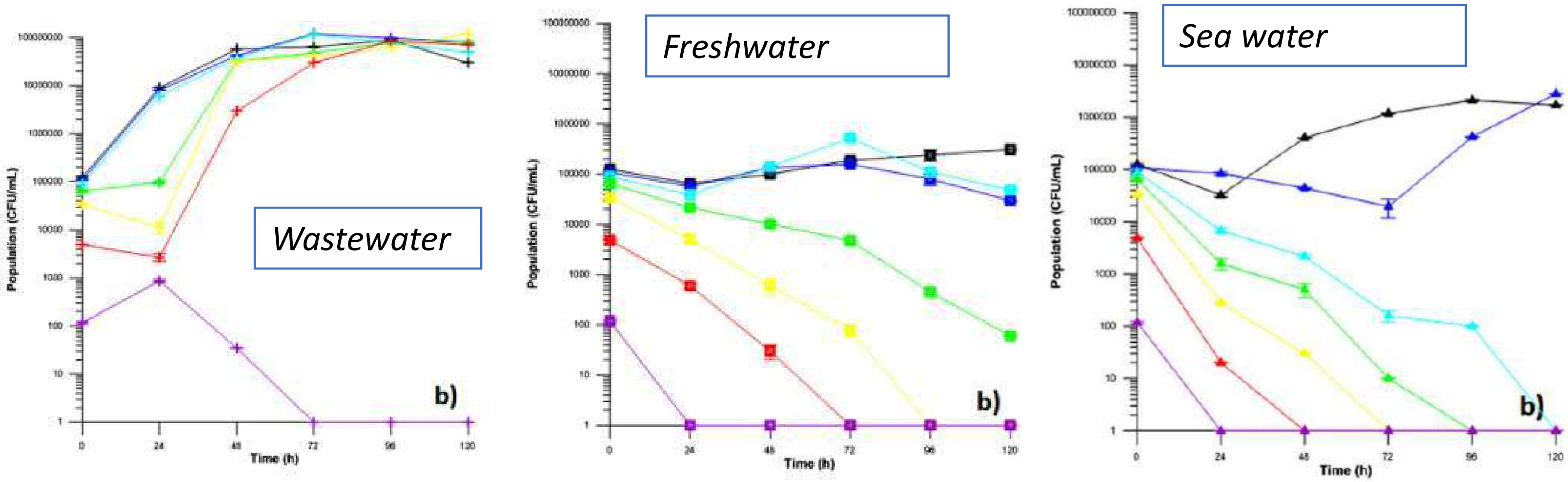
WASTEWATER

Microbial pollution

Co-funded by the Erasmus+ Programme of the European Union

Regrowth mostly depends on the environmental conditions and vary for different microorganisms.

E. coli



Giannakis, et al., Chem. Eng. J., 2014, 253, 366–376.

A few studies examining heterotrophic bacteria and indicated regrowth within hours to days after a successful disinfection treatment…

WASTEWATER

Contaminants of Emerging Concern

MEP&M · UCA Universidad de Cádiz · Co-funded by the Erasmus+ Programme of the European Union

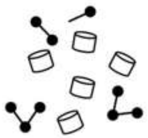
Micropollutants (MPs), also referred to as **contaminants of emerging concern (CECs)**
pollutants that exist in very small traces in water have been attracting the attention of the scientific community because of their frequent occurrence in the aquatic environment even after passing through conventional water and wastewater treatment systems.

[ng/L] or [μg/L]

Pharmaceutically active compounds (PhACs),

personal care products,

pesticides,



synthetic and natural hormones,

industrial chemicals (such as flame retardants, plasticizers, food additives, among others)

The release of CECs from WWTPs into the environment has not yet been regulated nor their occurrence in wastewater for agricultural reuse.

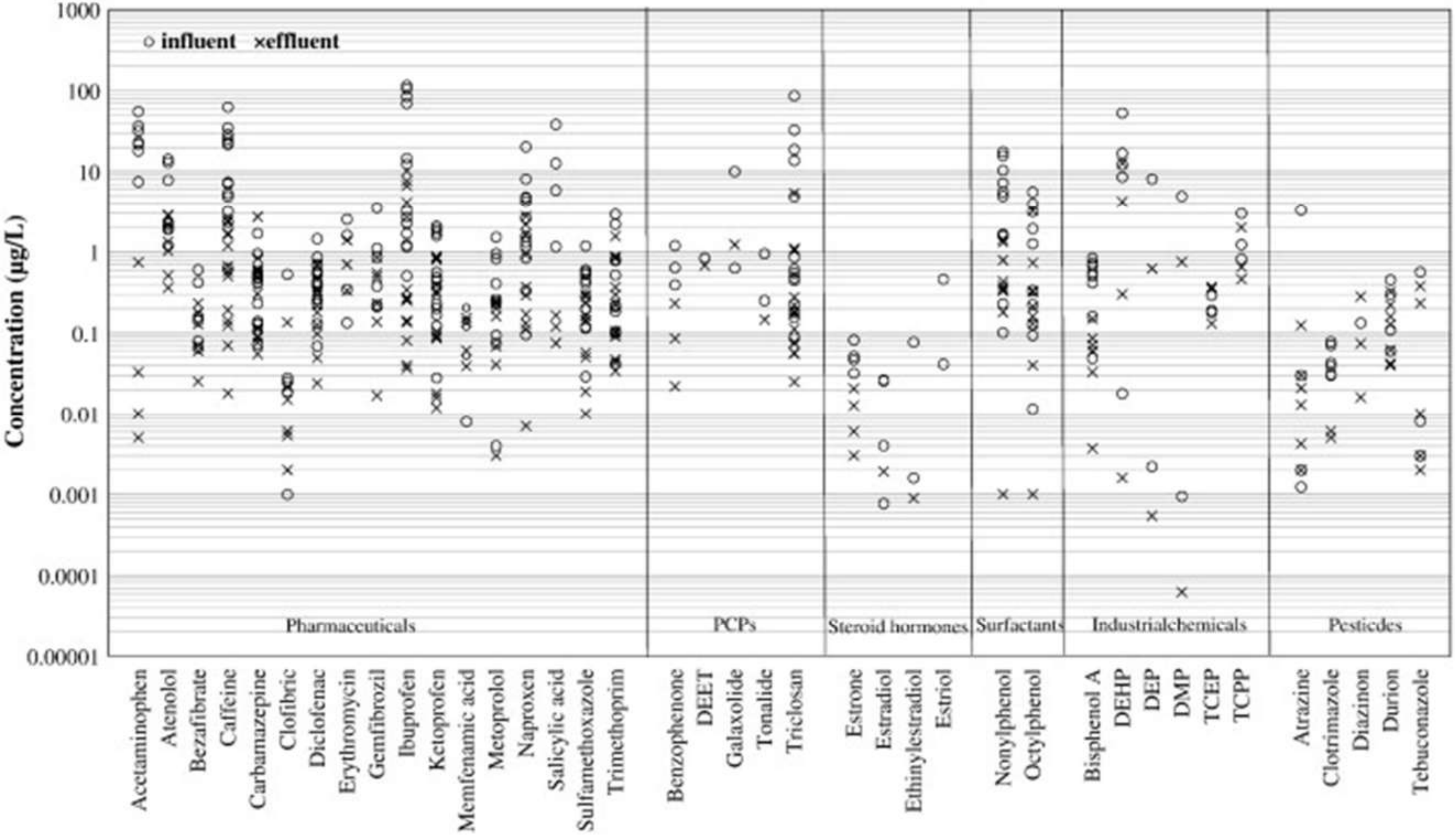
Conventional secondary (e.g., activated sludge process) and tertiary (such as filtration and disinfection) treatments in urban wastewater treatment plants (WWTPs) are not effective in the removal of most CECs entering WWTPs

Barbosa, et al. 2016. Water Res. 94, 257–279. https://doi.org/10.1016/j. watres.2016.02.047.
Luo, Y., et al.. (2014). Science of the total environment, 473, 619-641. https://doi.org/10.1016/j.scitotenv.2013.12.065
Rizzo, et al. 2019. Sci. Total Environ. 655, 986–1008, doi:10.1016/J.SCITOTENV.2018.11.265.

WASTEWATER

Contaminants of Emerging Concern

Co-funded by the Erasmus+ Programme of the European Union

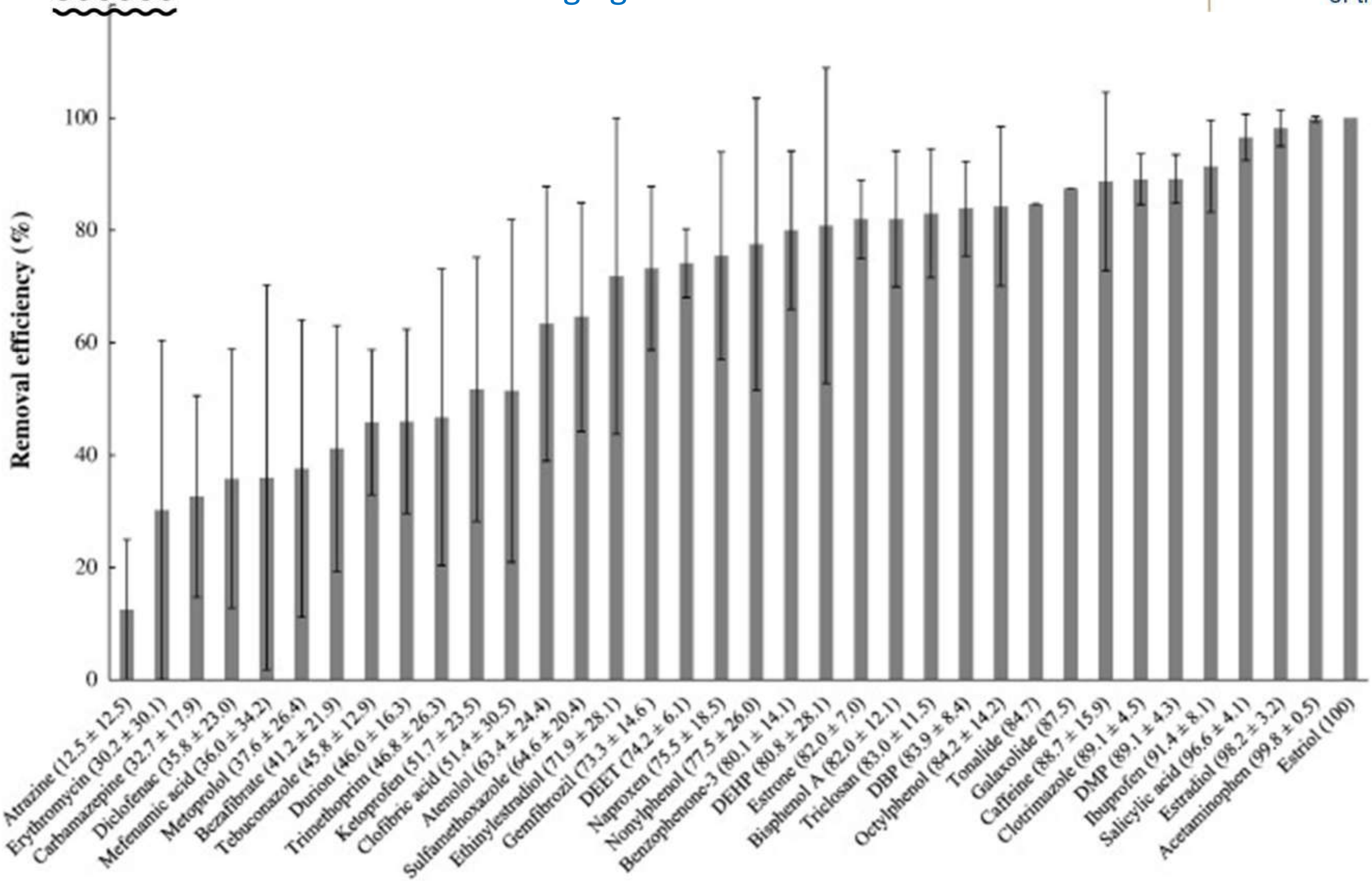


Luo, Y., et al.. (2014). Science of the total environment, 473, 619-641. https://doi.org/10.1016/j.scitotenv.2013.12.065

WASTEWATER

Contaminants of Emerging Concern

Co-funded by the Erasmus+ Programme of the European Union

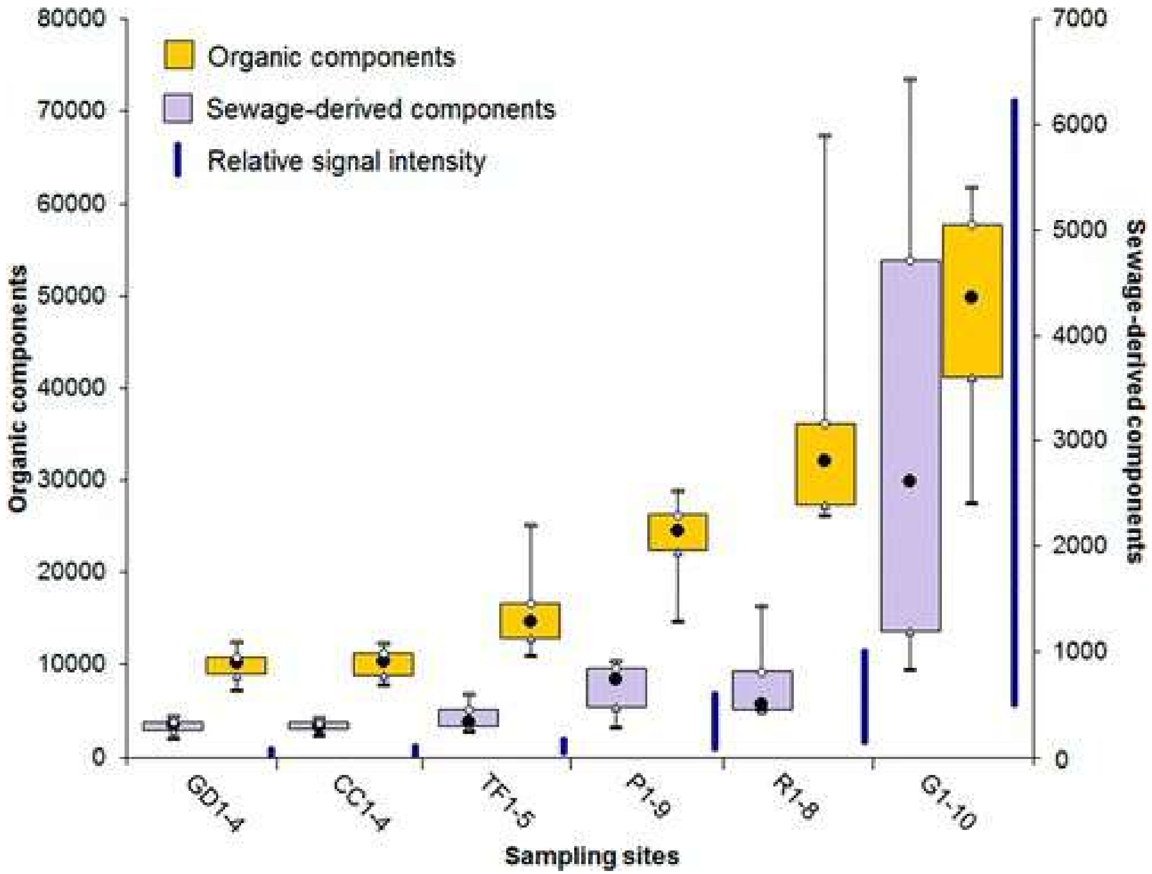


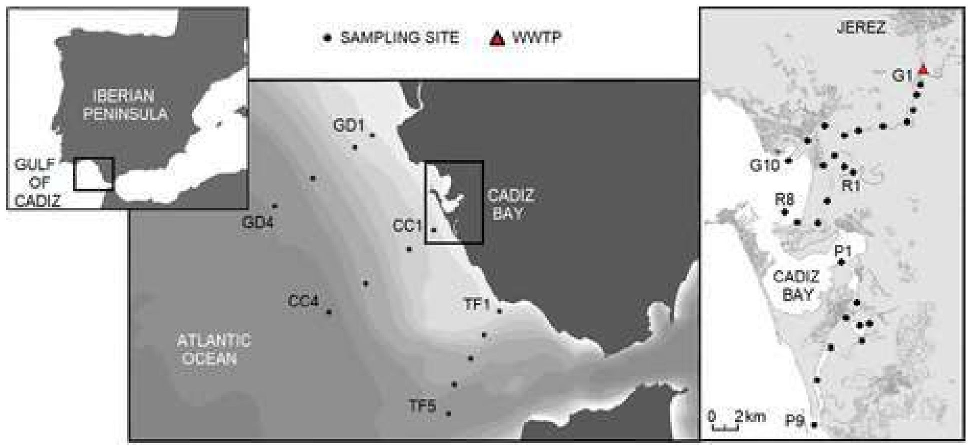
Luo, Y., et al.. (2014). Science of the total environment, 473, 619-641. https://doi.org/10.1016/j.scitotenv.2013.12.065

WASTEWATER

Contaminants of Emerging Concern

MEP&M | UCA Universidad de Cádiz | Co-funded by the Erasmus+ Programme of the European Union





Variability in the number of all organic compounds and potential sewage-derived contaminants detected in sampling stations at the Gulf of Cadiz

Lara-Martín, et al. Environ. Sci. Technol. 2020, doi:10.1021/acs.est.9b06114.

WASTEWATER

Contaminants of Emerging Concern

Co-funded by the Erasmus+ Programme of the European Union

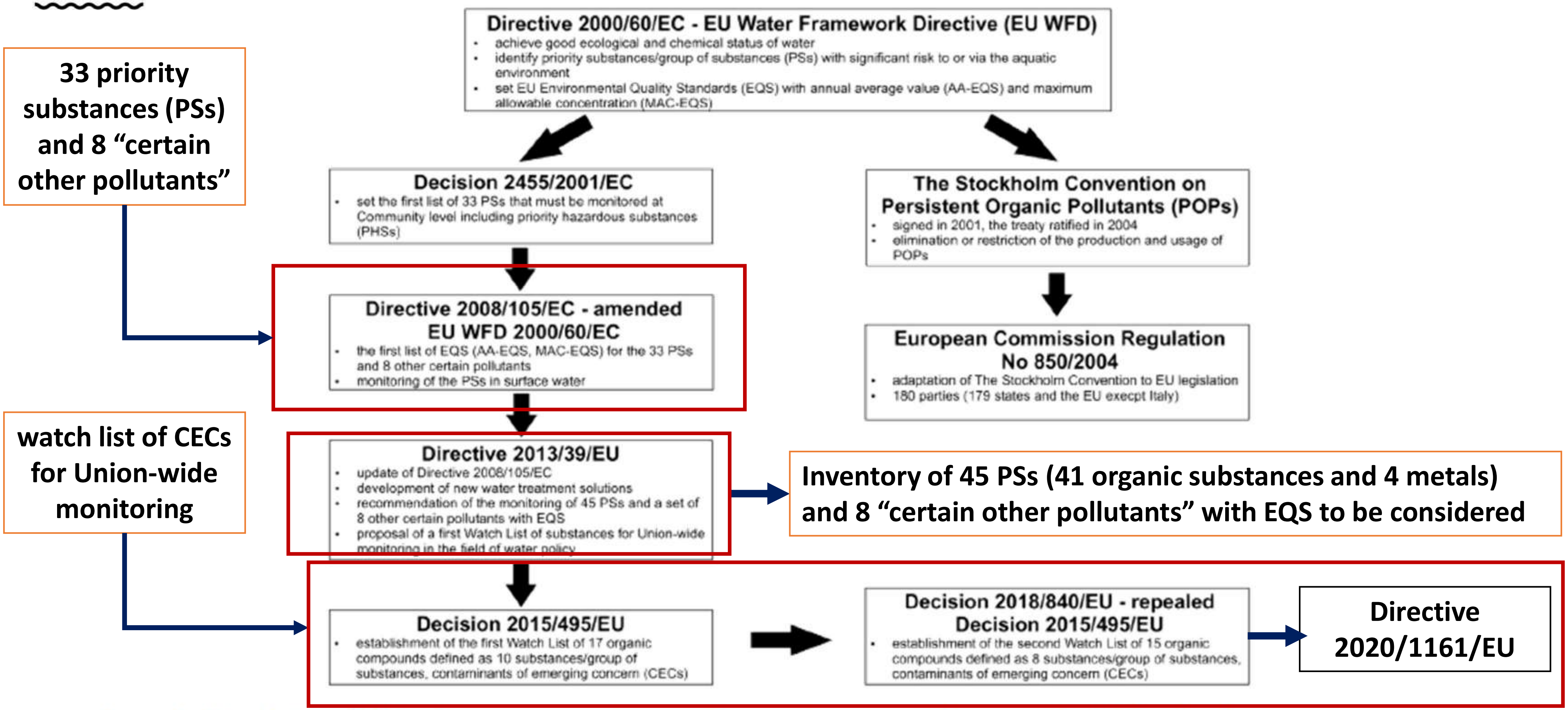


Figure 1. The evolution of EU legislation on water quality protection against priority substances over the last two decades.

Pietrzak et al. 2019. Clean–Soil, Air, Water,.

DIRECTIVE 2015/495/CE

ANNEX

Watch list of substances for Union-wide monitoring as set out in Article 8b of Directive 2008/105/EC

Name of substance/group of substances	CAS number (1)	EU number (2)	Indicative analytical method (3) (4) (5)	Maximum acceptable method detection limit (ng/l)
17-Alpha-ethinylestradiol (EE2)	57-63-6	200-342-2	Large-volume SPE — LC-MS-MS	0,035
17-Beta-estradiol (E2), Estrone (E1)	50-28-2, 53-16-7	200-023-8	SPE — LC-MS-MS	0,4
Diclofenac	15307-86-5	239-348-5	SPE — LC-MS-MS	10
2,6-Ditert-butyl-4-methylphenol	128-37-0	204-881-4	SPE — GC-MS	3 160
2-Ethylhexyl 4-methoxycinnamate	5466-77-3	226-775-7	SPE — LC-MS-MS or GC-MS	6 000
Macrolide antibiotics (6)			SPE — LC-MS-MS	90
Methiocarb	2032-65-7	217-991-2	SPE — LC-MS-MS or GC-MS	10
Neonicotinoids (7)			SPE — LC-MS-MS	9
Oxadiazon	19666-30-9	243-215-7	LLE/SPE — GC-MS	88
Tri-allate	2303-17-5	218-962-7	LLE/SPE — GC-MS or LC-MS-MS	670

MEP&M
UCA Universidad de Cádiz
Co-funded by the Erasmus+ Programme of the European Union

DIRECTIVE 2018/840/CE

Watch list of substances for Union-wide monitoring as set out in Article 8b of Directive 2008/105/EC

Name of substance/group of substances	CAS number (1)	EU number (2)	Indicative analytical method (3) (4)	Maximum acceptable method detection limit (ng/l)
17-Alpha-ethinylestradiol (EE2)	57-63-6	200-342-2	Large-volume SPE - LC-MS-MS	0,035
17-Beta-estradiol (E2), Estrone (E1)	50-28-2, 53-16-7	200-023-8	SPE - LC-MS-MS	0,4
Macrolide antibiotics (5)			SPE - LC-MS-MS	19
Methiocarb	2032-65-7	217-991-2	SPE - LC-MS-MS or GC-MS	2
Neonicotinoids (6)			SPE - LC-MS-MS	8,3
Metaflumizone	139968-49-3	604-167-6	LLE - LC-MS-MS or SPE – LC-MS-MS	65
Amoxicillin	26787-78-0	248-003-8	SPE - LC-MS-MS	78
Ciprofloxacin	85721-33-1	617-751-0	SPE - LC-MS-MS	89

WASTEWATER

Contaminants of Emerging Conc

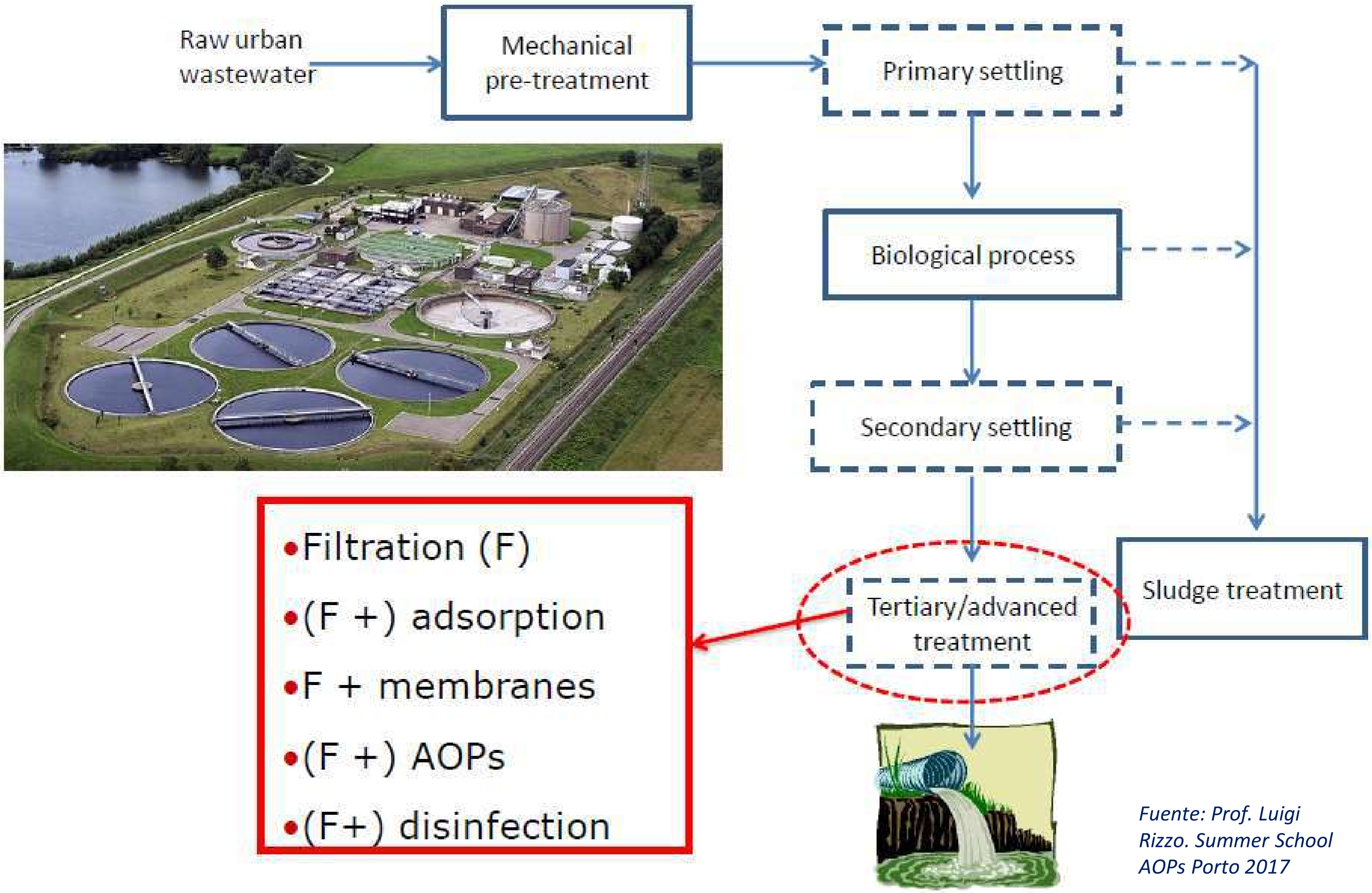
DIRECTIVE 2020/1161/CE

Name of substance/group of substances	CAS number (1)	EU number (2)	Indicative analytical method (3) (4)	Maximum acceptable method detection limit (ng/l)
Metaflumizone	139968-49-3	604-167-6	LLE-LC-MS-MS or SPE–LC-MS-MS	65
Amoxicillin	26787-78-0	248-003-8	SPE-LC-MS-MS	78
Ciprofloxacin	85721-33-1	617-751-0	SPE-LC-MS-MS	89
Sulfamethoxazole (5)	723-46-6	211-963-3	SPE-LC-MS-MS	100
Trimethoprim (5)	738-70-5	212-006-2	SPE-LC-MS-MS	100
Venlafaxine and O-desmethylvenlafaxine (6)	93413-69-5 93413-62-8	618-944-2 700-516-2	SPE-LC-MS-MS	6
Azole compounds (7)			SPE-LC-MS-MS	
Clotrimazole	23593-75-1	245-764-8		20
Fluconazole	86386-73-4	627-806-0		250
Imazalil	35554-44-0	252-615-0		800
Ipconazole	125225-28-7	603-038-1		44
Metconazole	125116-23-6	603-031-3		29
Miconazole	22916-47-8	245-324-5		200
Penconazole	66246-88-6	266-275-6		1 700
Prochloraz	67747-09-5	266-994-5		161
Tebuconazole	107534-96-3	403-640-2		240
Tetraconazole	112281-77-3	407-760-6		1 900
Dimoxystrobin	149961-52-4	604-712-8	SPE-LC-MS-MS	32
Famoxadone	131807-57-3	603-520-1	SPE-LC-MS-MS	8,5

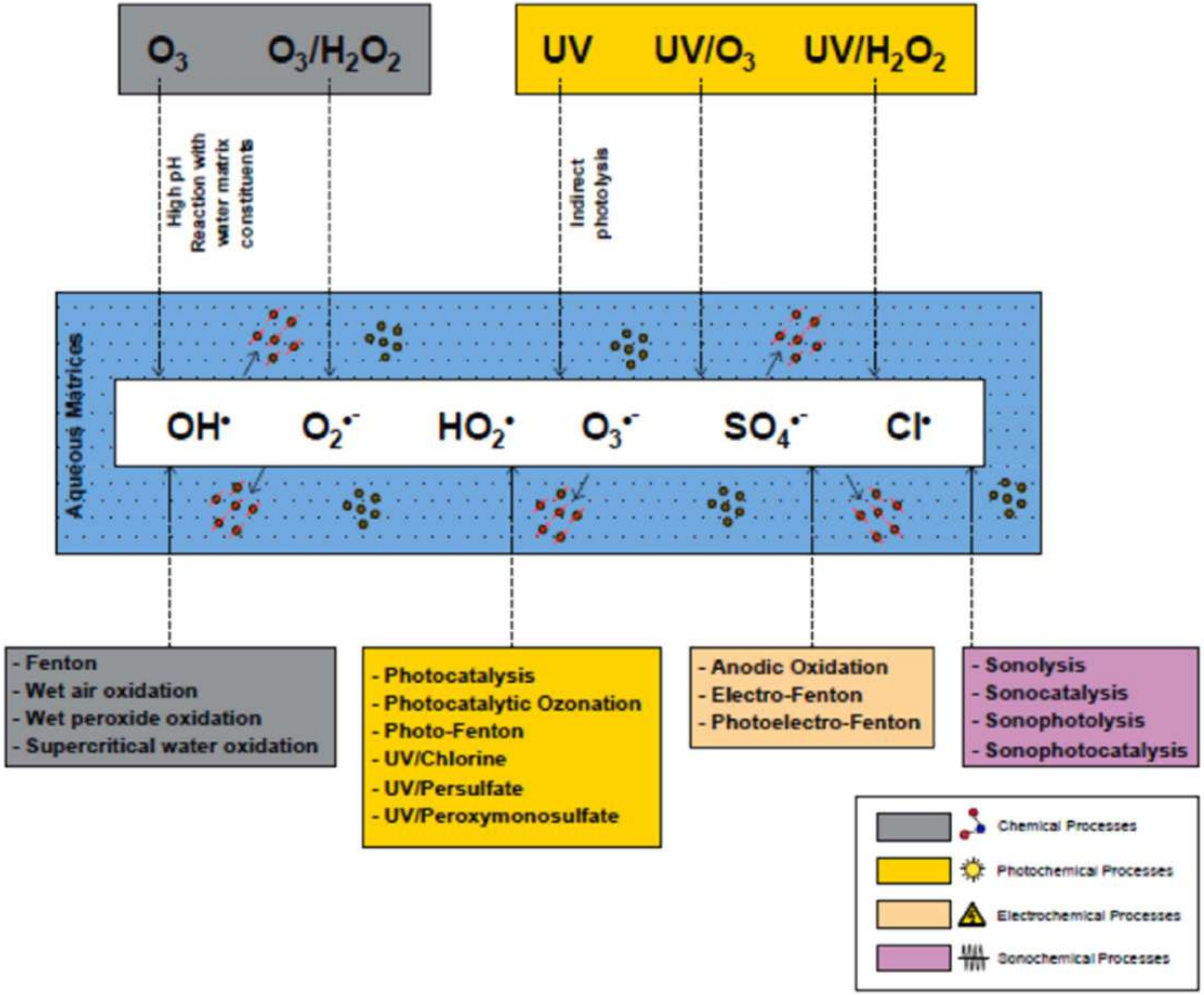
(1) Chemical Abstracts Service.
(2) European Union number.
(3) To ensure comparability of results from different Member States, all substances shall be monitored in whole water samples.
(4) Extraction methods:
LLE – liquid liquid extraction
SPE – solid-phase extraction
Analytical methods:
LC-MS-MS – Liquid chromatography (tandem) triple quadrupole mass spectrometry.
(5) Sulfamethoxazole and trimethoprim shall be analysed together in the same samples but reported as individual concentrations.
(6) Venlafaxine and O-desmethylvenlafaxine shall be analysed together in the same samples but reported as individual concentrations.
(7) The azole compounds shall be analysed together in the same samples but reported as individual concentrations.

Tertiary treatment in UWWTPs

Co-funded by the Erasmus+ Programme of the European Union

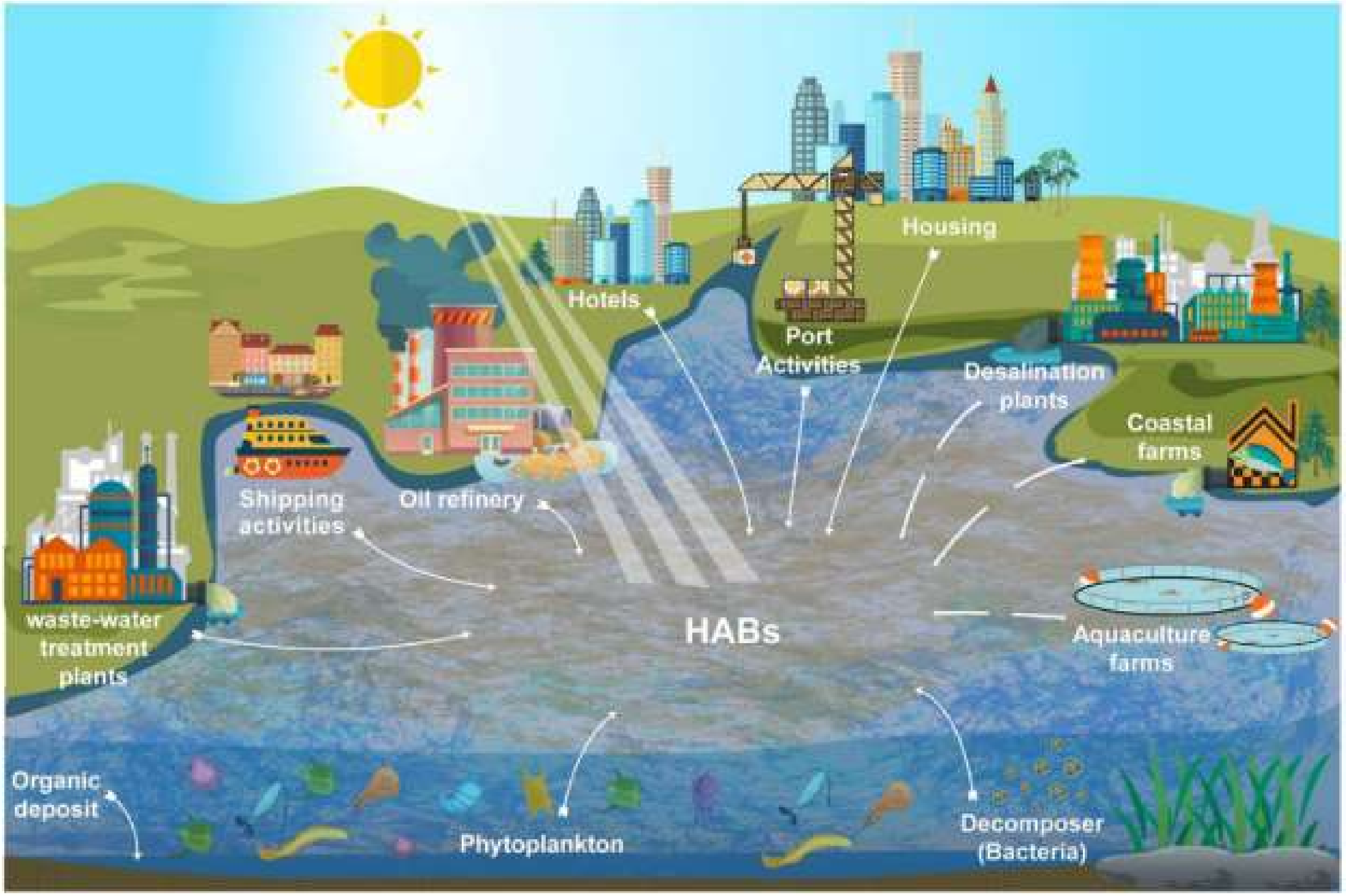


Fuente: Prof. Luigi Rizzo. Summer School AOPs Porto 2017



Co-funded by the Erasmus+ Programme of the European Union

Gorito et al. Environ. Res. 2022, 204, 111955



Trottet, Crit. Rev. Environ. Sci. Technol. 2021, 1–42

WASTEWATER

MARITIME TRANSPORT

AQUACULTURE FACILITIES

Co-funded by the Erasmus+ Programme of the European Union

MARITIME TRANSPORT

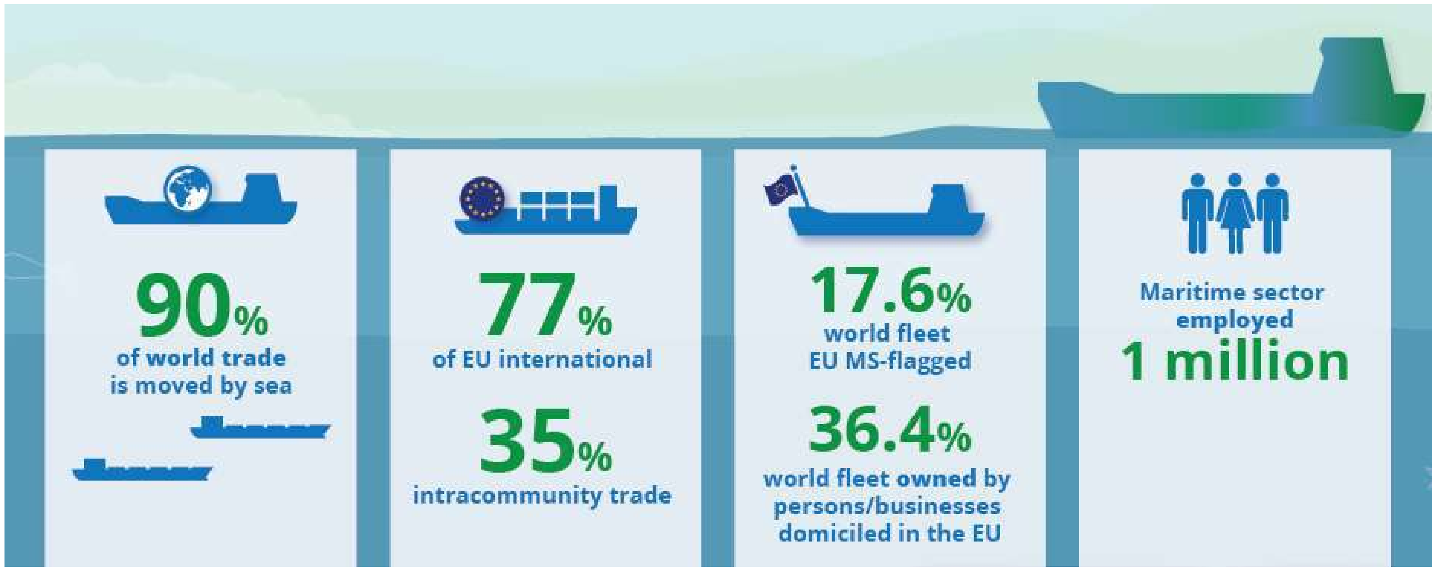
Co-funded by the Erasmus+ Programme of the European Union

Maritime transport is essential for EU and global trade...

... continuously expanding through the globe

Figure 3.2 **Number of ships and total GT of ships under EU Member State flags**

European Maritime Transport Environmental Report 2021. EMSA



MARITIME TRANSPORT

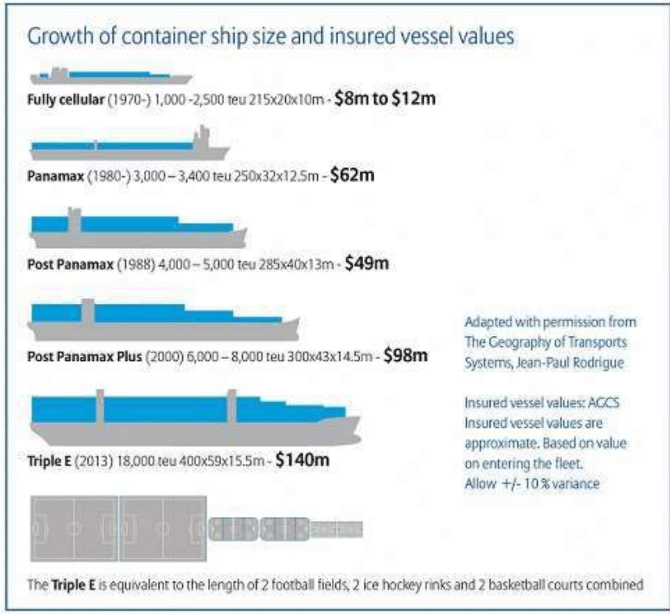
Co-funded by the

Maritime transport is continuously expanding through the globe

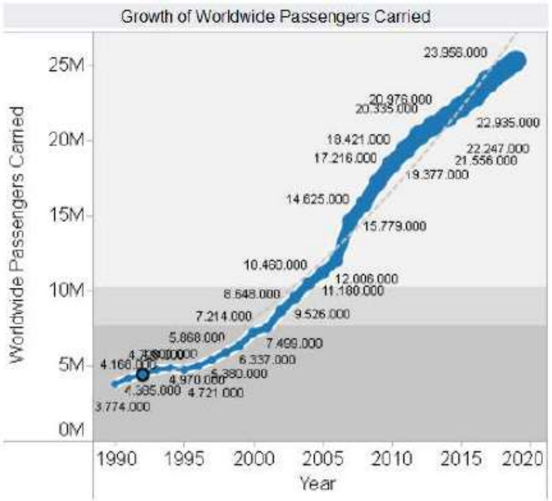
CARGO SHIPS

It covers (UE) about **90% of total world merchandise**

EMSA/EEA 2021



CRUISE TOURISM INDUSTRY



Source: Cruise Market Watch

Exponential Growth

437 million people embarking (or disembarking) in EU ports in 2018.

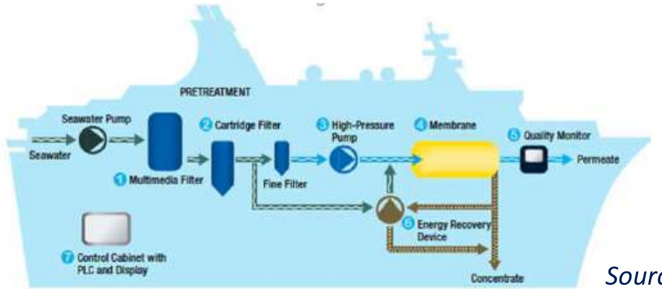
More than half of all EU port calls are made by roll-on, roll-off passenger and cruise ships.

EMSA/EEA 2021

MARITIME TRANSPORT

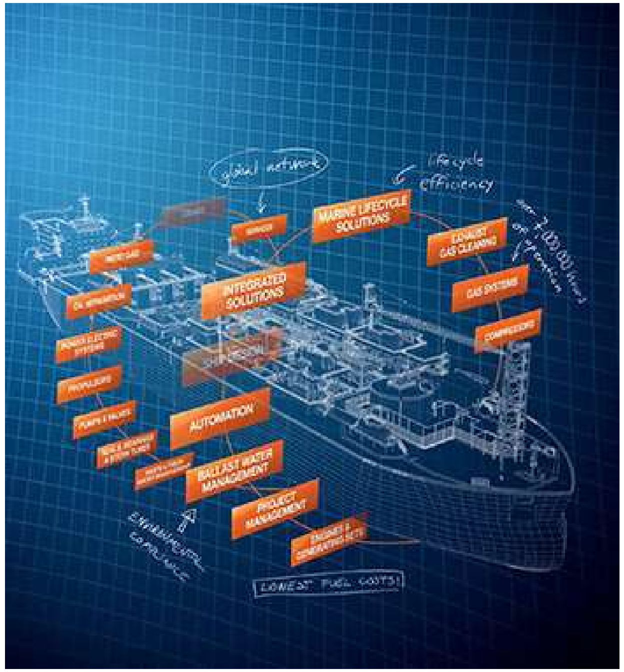
Co-funded by the Erasmus+ Programme of the European Union

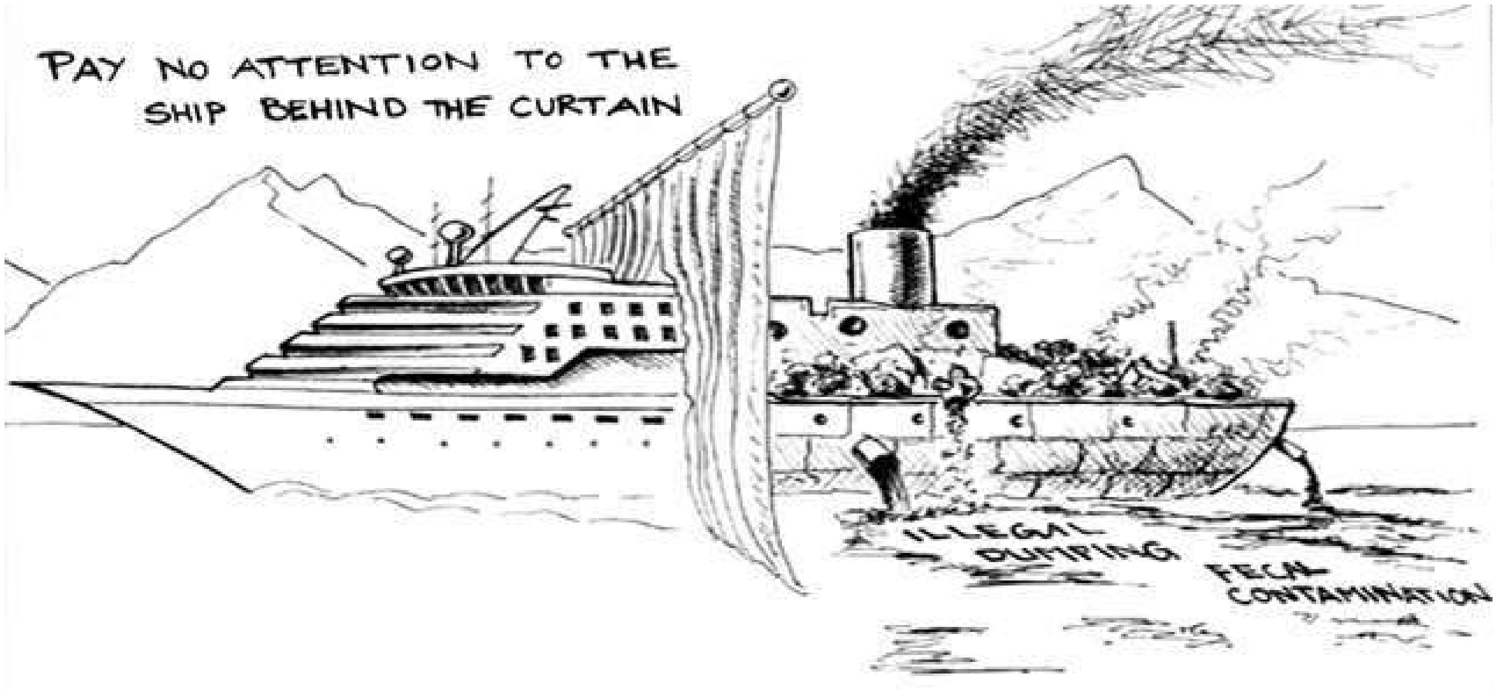
WATER MANAGEMENT



Source: EVAC

Use of water in vessels implies the needs to discharge it





These environmental pressures could be enough to constitute a **health hazard to the ecosystem** and increase **marine pollution**

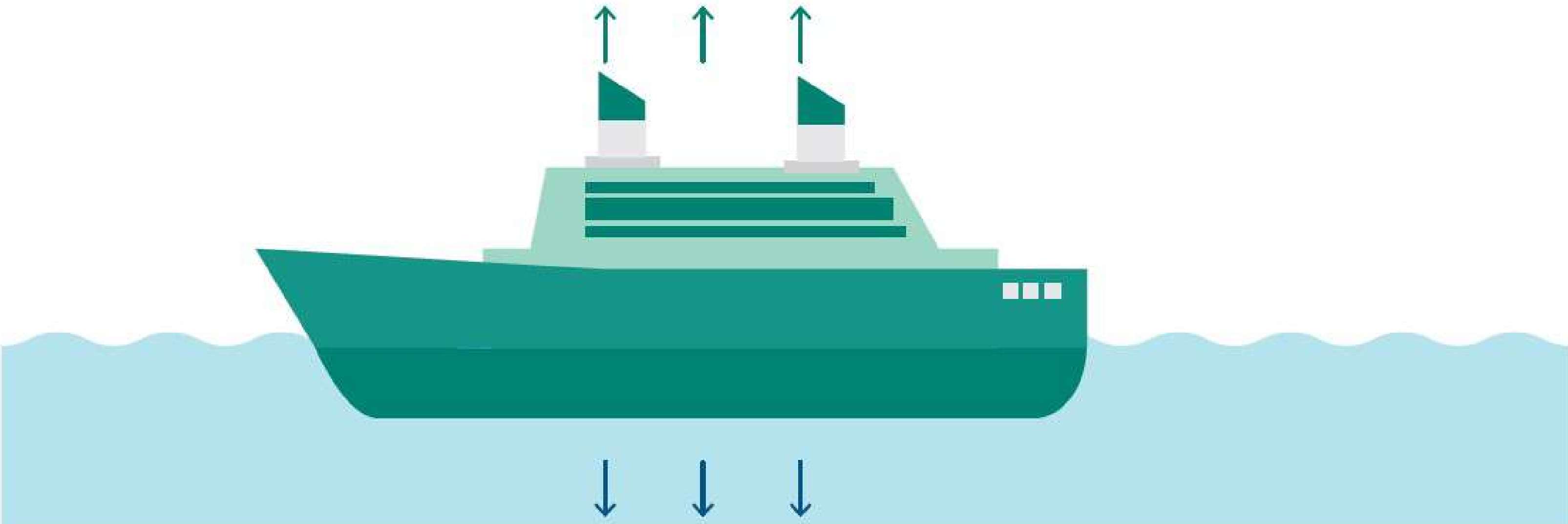
Co-funded by the
Erasmus+ Programme
of the European Union

Figure 4.1 Pollutant emissions to the atmosphere and water body from a generic ship

Emissions to the atmosphere,
typically designated air emissions, constituting of greenhouse gases and air pollutants (other relevant substances).

GHG (Greenhouse gases) — CO_2 (Carbon dioxide), CH_4 (Methane), N_2O (Nitrous oxide), HFCs (Hydrofluorocarbons), PFCs (Perfluorocarbons) and SF_6 (Sulphur hexafluoride).

Air pollutants and other relevant substances — NO_x (Nitrogen oxides), SO_x (Sulphur oxides), NMVOC (Non-methane volatile organic compounds), CO (Carbon monoxide) and PM (Particulate matter, including black carbon).



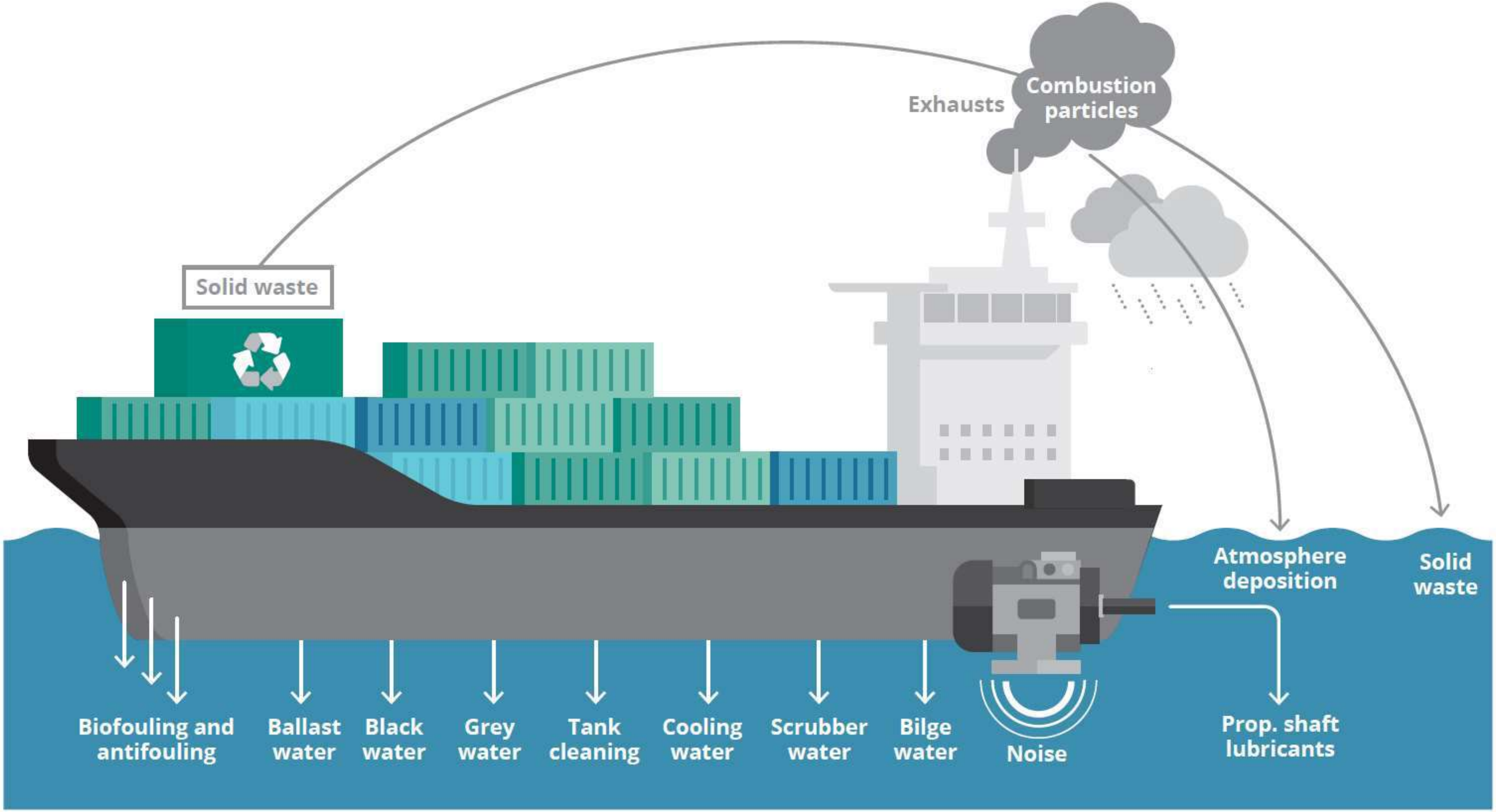
Emissions to the surrounding water body,
in the shape of discharges, biocide effect of persistent anti-fouling components, invasive species.

Oil and oily waters
Sewage and other
Ballast water (invasive species with impact over the ecosystems)
Antifouling compounds (influence of TBT/heavy metals from AFS in ecosystems)
Solid residues (waste and other solid residues)
Operational residue waters (such as Scrubber washwater)
Dangerous substances/goods
Underwater radiated noise

European Maritime Transport Environmental Report 2021. EMSA

Source: EMSA/EEA (2021).

Figure 4.16 Subsystems on board ships that produce water pollution



Source: SHEBA project (2018).

European Maritime Transport Environmental Report 2021. EMSA

MEP&M
UCA Universidad de Cádiz
Co-funded by the Erasmus+ Programme of the European Union

Sewage

Ballast Waters

Scrubber waters

Black and Grey water

Importance of (micro)organisms

… Oil and hazardous and noxious substances spills

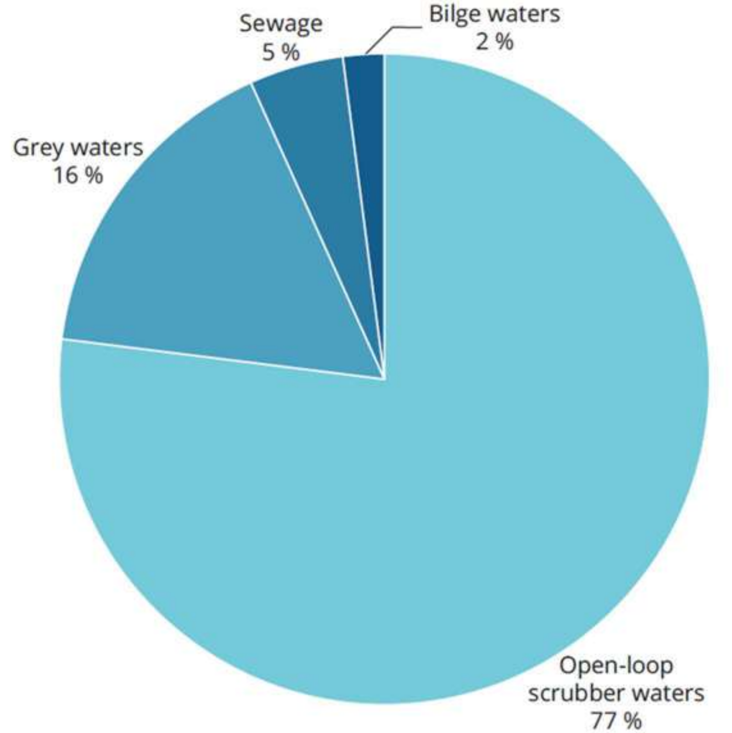
18 major accidental spills worldwide since 2010, only 3 occurred in the EU (17 %)

Better monitoring, enforcement and awareness raising contribute to reducing oil pollution incidents, despite the fact that the amount of oil transported by sea has progressively increased over the last 30 years.

Antifouling (Metal)

Mainly copper and zinc compounds

Figure 4.17 **Share of estimated water discharges from ships, 2019**



Source: STEAM (2021).

European Maritime Transport Environmental Report 2021. EMSA

Table 4.7 **Overview of the amounts of ship-generated waste, drivers and treatment methods**

Type of waste	Generation rate	Driver	On-board treatment
Oily bilge water	0.01-13 m^3 per day; larger ships generate larger quantities	Condensation and leakages in the engine room; size of the ship	The amount can be reduced by 65-85 % by using an oil-water separator and discharging the water fraction into the sea
Oily residues (sludge)	0.01-0.03 m^3 of sludge per tonne of heavy fuel oil 0 and 0.01 m^3 per tonne of marine gas oil	Type of fuel; fuel consumption	Evaporation can reduce the amount of sludge by up to 75 %. Incineration can reduce the amount of sludge by 99 % or more
Tank washings (slops)	20 m^3 to hundreds of cubic metres	Number of tank cleanings; size of loading capacity	After settling, the water fraction may be discharged at sea.
Sewage	0.01-0.06 m^3 per person per day. Sewage is sometimes mixed with other waste water. The total amount ranges from 0.04 to 0.45 m^3 per day per person	Number of people on board; type of toilets; length of voyage	Effluent from treatment plants is often discharged at sea where permitted
Plastics	0.001-0.008 m^3 of plastics per person per day	Number of people on board	Often not incinerated. Dirty plastics (plastics that have been in contact with food) are often treated as a separate waste stream
Food wastes	0.001-0.003 m^3 per person per day	Number of people on board; provisions	Where permitted, food waste is often discharged at sea
Domestic wastes	0.001-0.02 m^3 per day per person	Number of people on board; type of products used	
Cooking oil	0.01-0.08 litres per person per day	Number of people on board; type of food prepared	Although not permitted, cooking oil is sometimes still added to the sludge tank
Incinerator ashes	0.004-0.06 m^3 per month	Use of incinerator; cost of using incinerator	The incinerator is not used for all types of waste, but mostly for paper and sometimes for sludge
Operational wastes	0.001-0.1 m^3 per person per day	Size of the ship; type of cargo	
Cargo residues	0.001-2 % of cargo load	Type of cargo; size of ship	

Co-funded by the Erasmus+ Programme of the European Union

UCA Universidad de Cádiz

MEP&M

European Maritime Transport Environmental Report 2021. EMSA

MARITIME TRANSPORT
Sewage

Co-funded by the Erasmus+ Programme of the European Union

Table 1. Mean pollutants production rates reported by cruise industry and environmental agencies.

Variable	No. vessels	No. reports	Min.	Mean	Max.	SD	Units
Black water[a]	125	8	36.0	64.9	111.0	24.4	L person^{-1} day^{-1}
Grey water[a]	125	8	129.0	159.6	212.2	24.3	L person^{-1} ·day^{-1}
Bilge water	100	8	11.3	22.8	25.6	4.4	L nautical mile^{-1}
CO_2	122	9	0.2	0.34	0.9	0.2	kg ALB^{-1} km^{-1}
SO_x	100	8	5.8	11.8	16.4	4.7	kg nautical mile^{-1}
NO_x	100	8	9.1	17.8	22.4	5.5	kg nautical mile^{-1}
$PM_{2.5}$	100	8	0.2	0.3	0.4	0.1	kg nautical mile^{-1}
Solid waste	122	9	3.2	9.5	51.7	15.0	kg person^{-1} day^{-1}
Fuel	122	9	77.3	82.6	84.2	2.4	g ALB^{-1} km^{-1}

[a]Include environmental agencies pollutant productions rates.
ALB, available lower berth. Corresponds to the nominal capacity of a cruise ship.

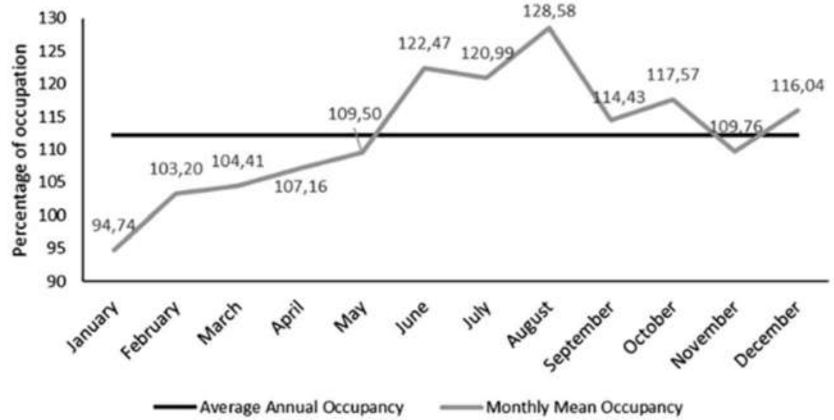


Figure 2. Average of the annual and monthly occupation for the ports analyzed (2015). The horizontal line represents the average annual occupation (112.15%). Take note that the vertical axis begins at 90%.

Vicente-Cera et al. Int. J. Sustain. Transp. 2019, 0, 1–10, doi:10.1080/15568318.2019.1575494.

MARITIME TRANSPORT
Sewage

MEP&M | UCA Universidad de Cádiz | Co-funded by the Erasmus+ Programme of the European Union

https://www.princess.com/

Guests 2 200

Crew 900

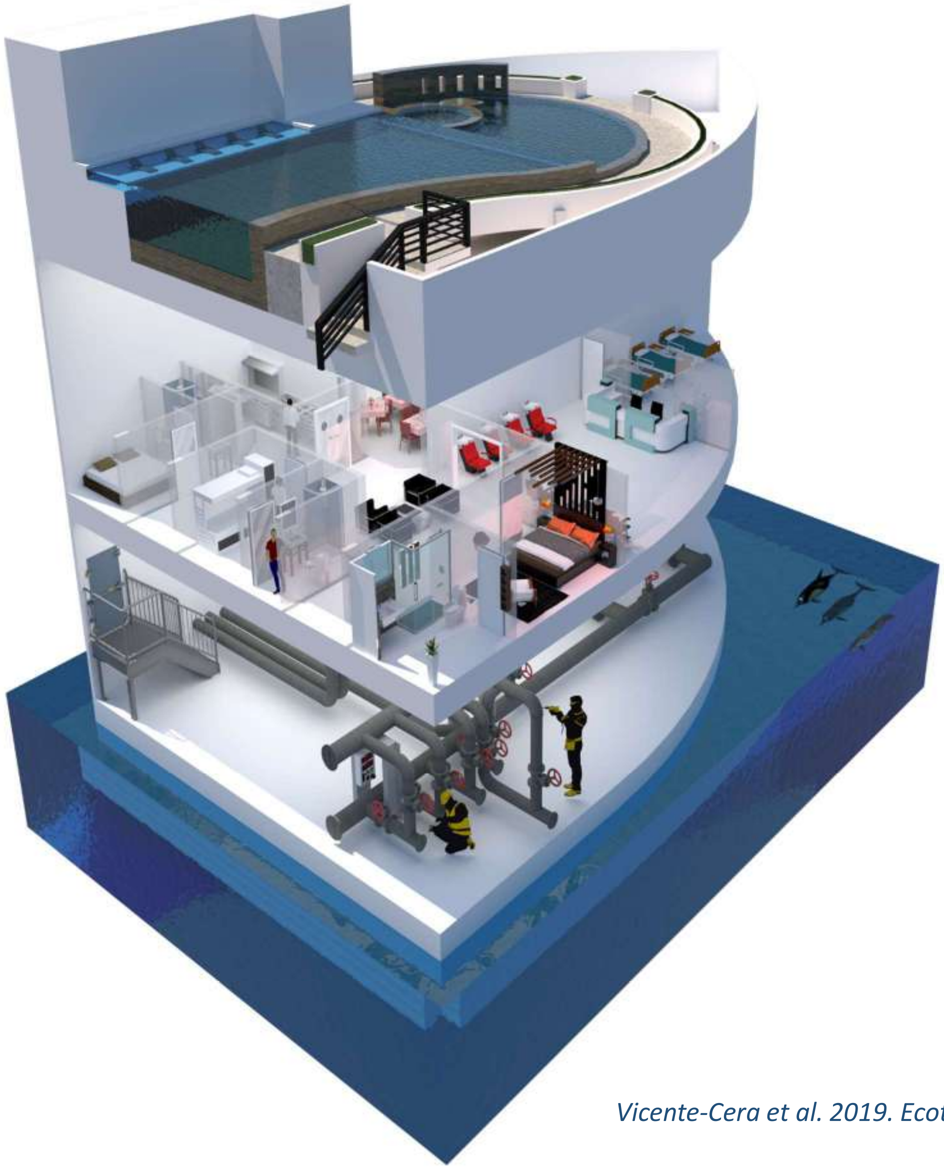
Sampling Episode Report Princess Cruise Lines - Island Princess Sampling Episode 6505. USEPA. March 2006

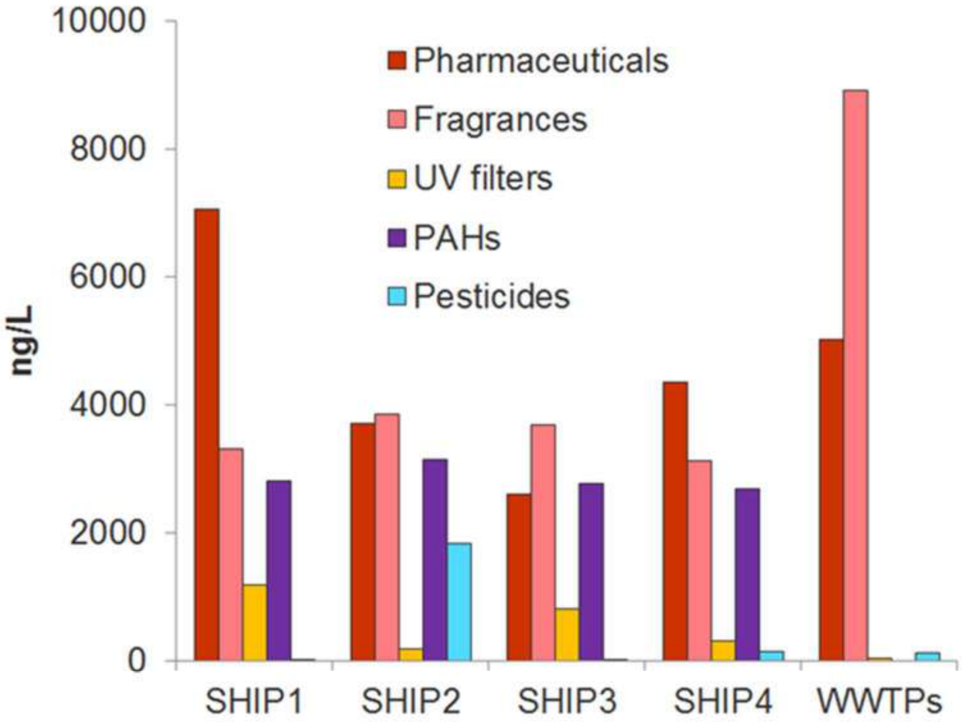
Chart 3. Comparison of Influent to Island Treatment System to Untreated Domestic Wastewater

Parameter	Untreated Island Wastewater	Untreated Domestic Wastewater (a)
Enterococci	10^6 to 10^7 MPN/100 mL	10^2 to 10^3 number/100 mL
Fecal Coliform	10^7 to 10^8 CFU/100 mL	10^4 to 10^5 number/100 mL
Ammonia	69.6 to 139 mg/L	12 to 50 mg/L
Biological Oxygen Demand (BOD_5)	224 to 409 mg/L	110 to 400 mg/L
Chemical Oxygen Demand (COD)	546 to 1,560 mg/L	250 to 1,000 mg
Nitrate/Nitrite	ND to 0.1 mg/L	0 mg/L
Oil and Grease	59.2 to 269 mg/L	50 to 150 mg/L
Total Phosphorus	16.6 to 71.6 mg/L	4 to 15 mg/L
Total Suspended Solids (TSS)	860 to 1,560 mg/L	100 to 350 mg/L

(a) Source: Metcalf & Eddy, *Wastewater Engineering*, Third Edition, 1991.
ND - Not detected.

Co-funded by the Erasmus+ Programme of the European Union

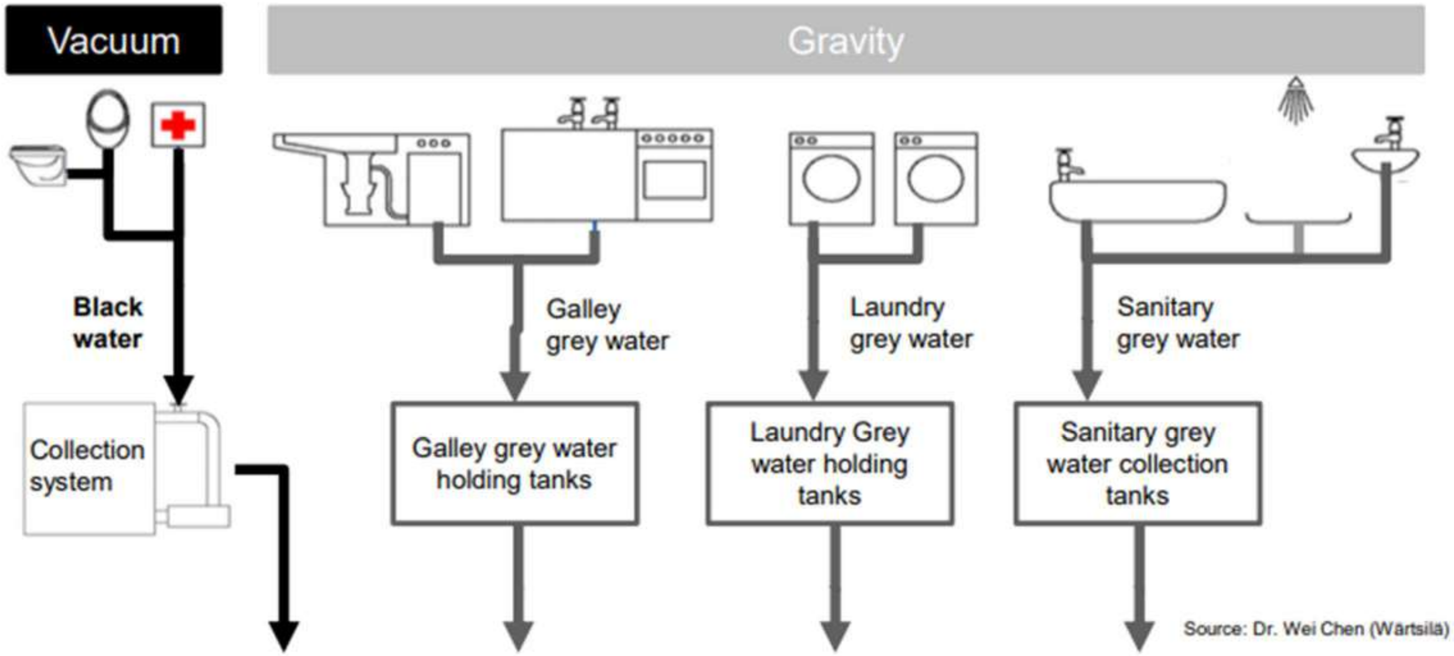




	E. coli	*Enterococci*	*Total Coliforms*
	CFU·100 mL^{-1}	CFU·100 mL^{-1}	CFU·100 mL^{-1}
C1	4.40E+05	3.93E+04	4.70E+06
C2	7.17E+06	4.88E+04	7.55E+08
C3	1.32E+08	1.04E+05	1.20E+08
C4	1.59E+05	1.82E+04	1.04E+06

Vicente-Cera et al. 2019. Ecotoxicol. Environ. Saf. 169, 68–75.

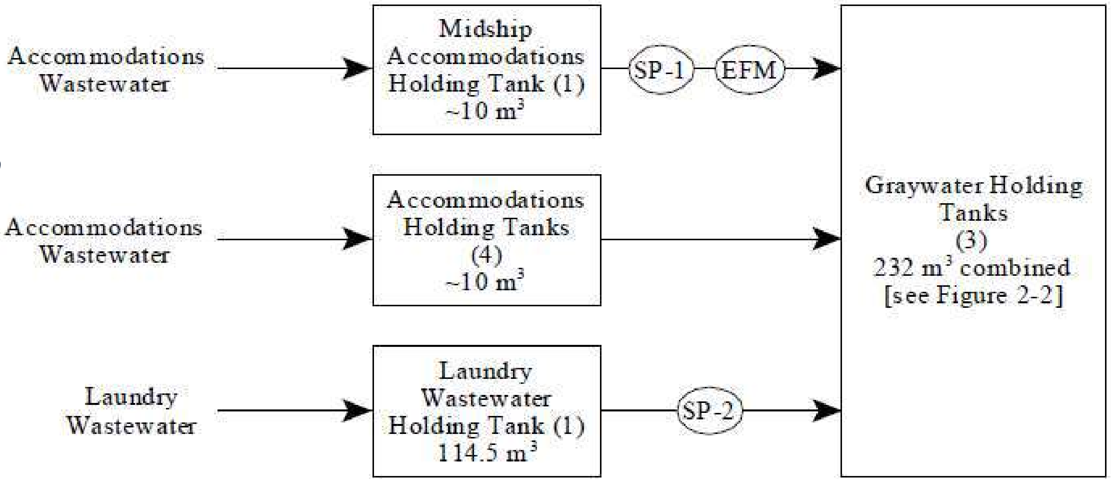
MEP&M
UCA Universidad de Cádiz
Co-funded by the Erasmus+ Programme of the European Union

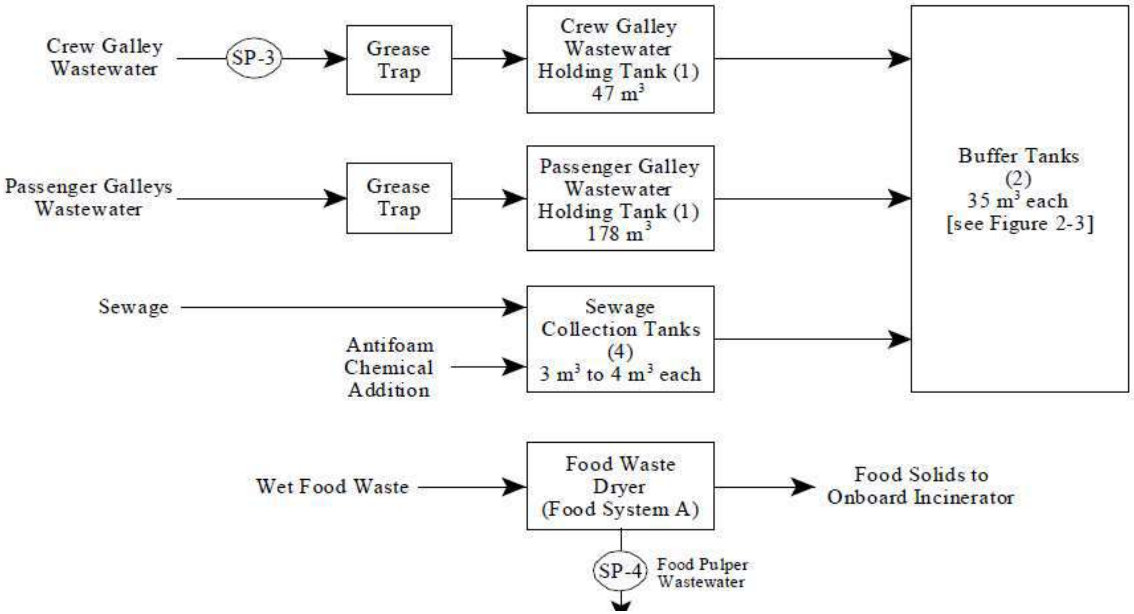


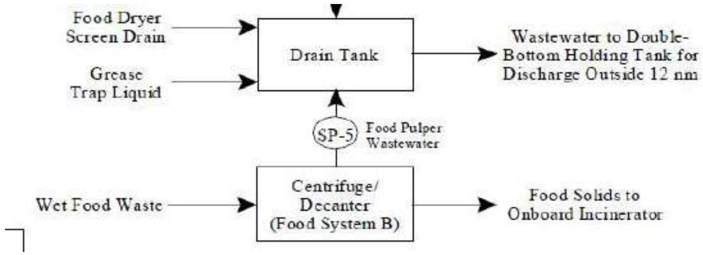
MARITIME TRANSPORT
Sewage

Sampling Episode Report
Holland America Oosterdam
Sampling Episode 6506
USEPA. March 2006

Guest: 1964
Length: 285 mt.
Width: 32 mt.
hollandamerica.com







Graywater and Sewage Collection, Holding, and Transfer System – Holland America Oosterdam

MARITIME TRANSPORT
Sewage

Co-funded by the Erasmus+ Programme of the European Union

MSD (Marine Sanitation Device)

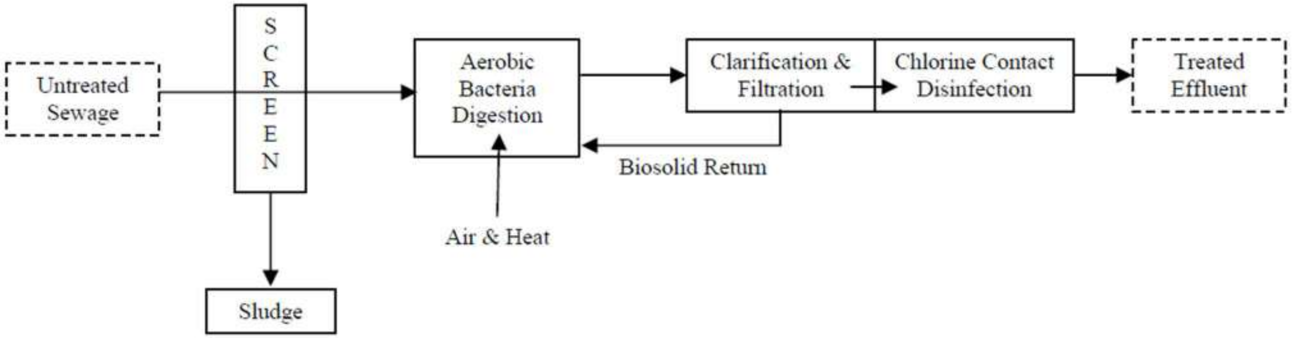


Figure 2-3. Simplified Schematic of Traditional Type II Marine Sanitation Device Using Biological Treatment and Chlorine Disinfection

AWTs
(Advanced Wastewater Treatment System)

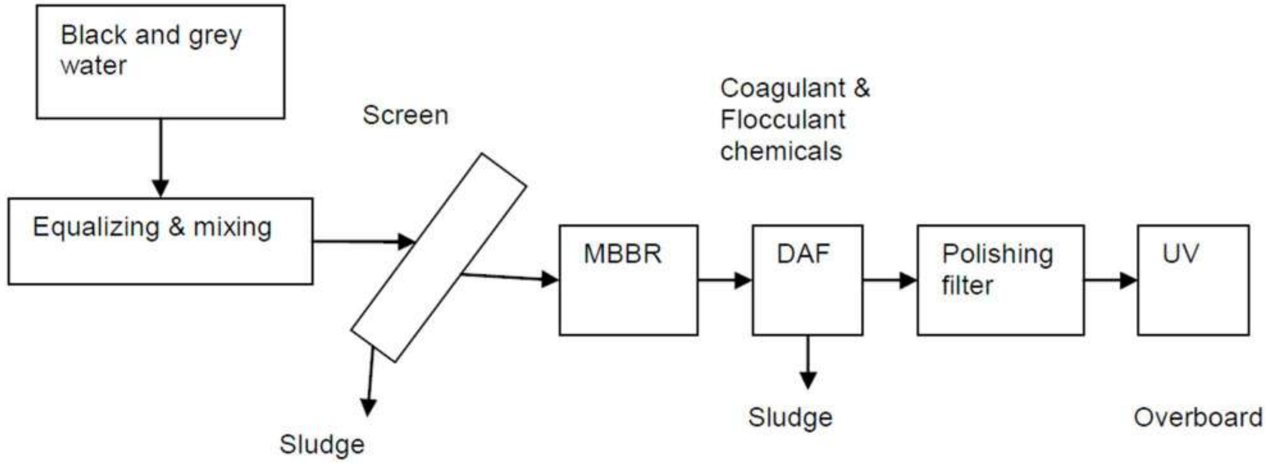


Figure 4-3. The principle of the moving bed bioreactor and flotation system (Kiukas, 2005).

WÄRTSILÄ Waste, Oil & Fresh Water Management

WÄRTSILÄ HAMWORTHY MEMBRANE BIOREACTOR (MBR) TECHNOLOGY

Queen Mary 2
(2620 pax. + 1253 trip.)

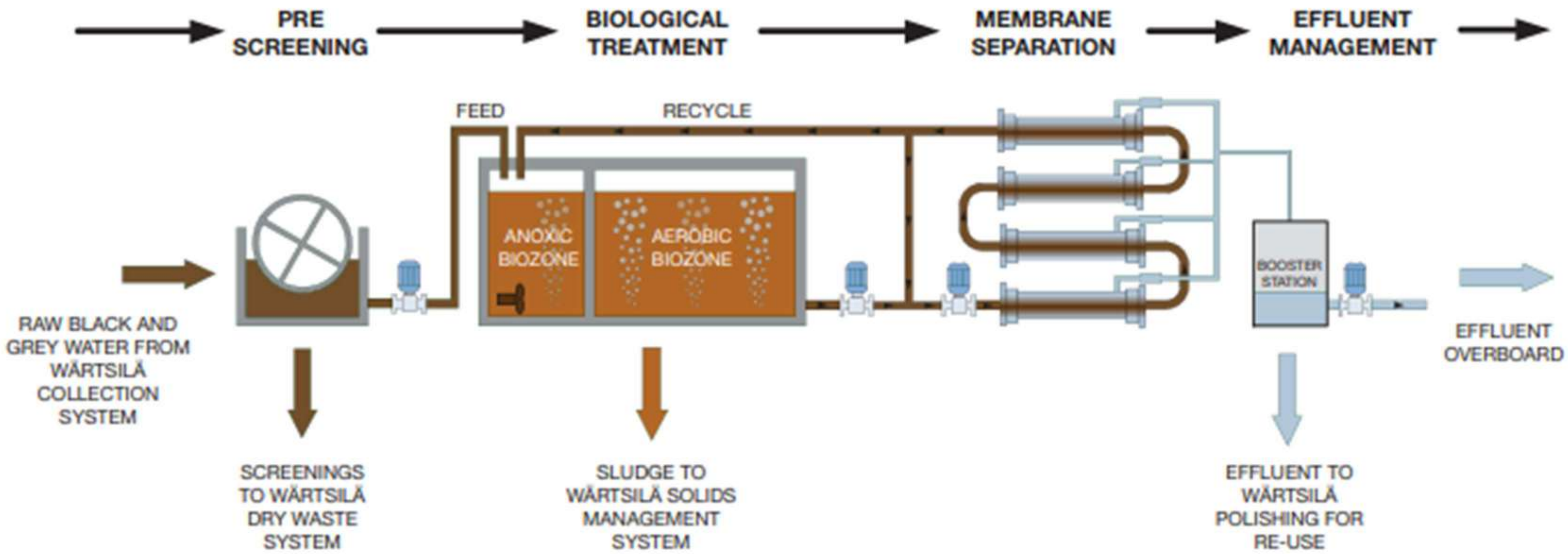
Co-funded by the Erasmus+ Programme of the European Union

Costas Españolas:

Emerald Princess

Island Princess
(1974 pax. + 900 trip.)

Membrane bioreactor



MARITIME TRANSPORT
Sewage

Co-funded by the Erasmus+ Programme of the European Union

Headworks BIO CLEANSEA
INTEGRATED SHIPBOARD WASTEWATER TREATMENT

Evac

MBBR
Moving Bed Bioreactor

MBBR
(Moving Bed Biofilm Reactor)

Costas Españolas:

Allure of the Seas
(5400 pax. + 2384 trip.)

Rhapsody of the Seas
(1435 pax. + 765 trip.)

Vision of the Seas
(2435 pax. + 660 trip.)

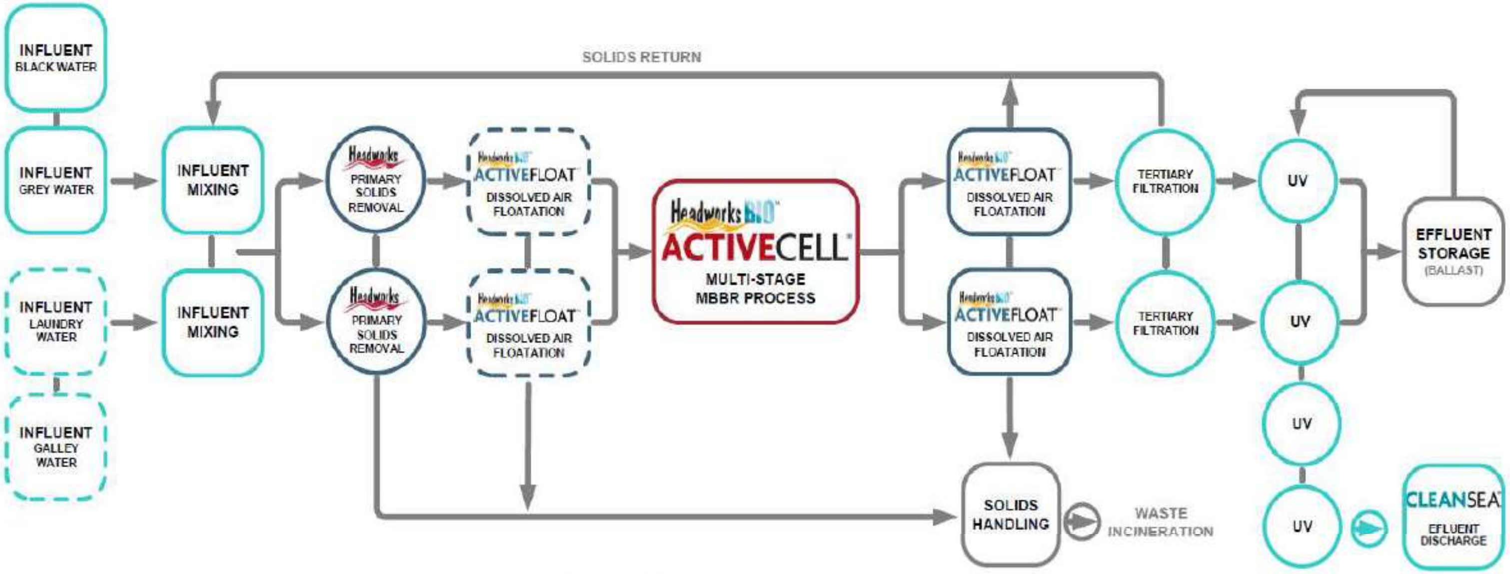
Celebrity Cruises

Royal Caribbean International

MARITIME TRANSPORT

Sewage

Co-funded by the Erasmus+ Programme of the European Union



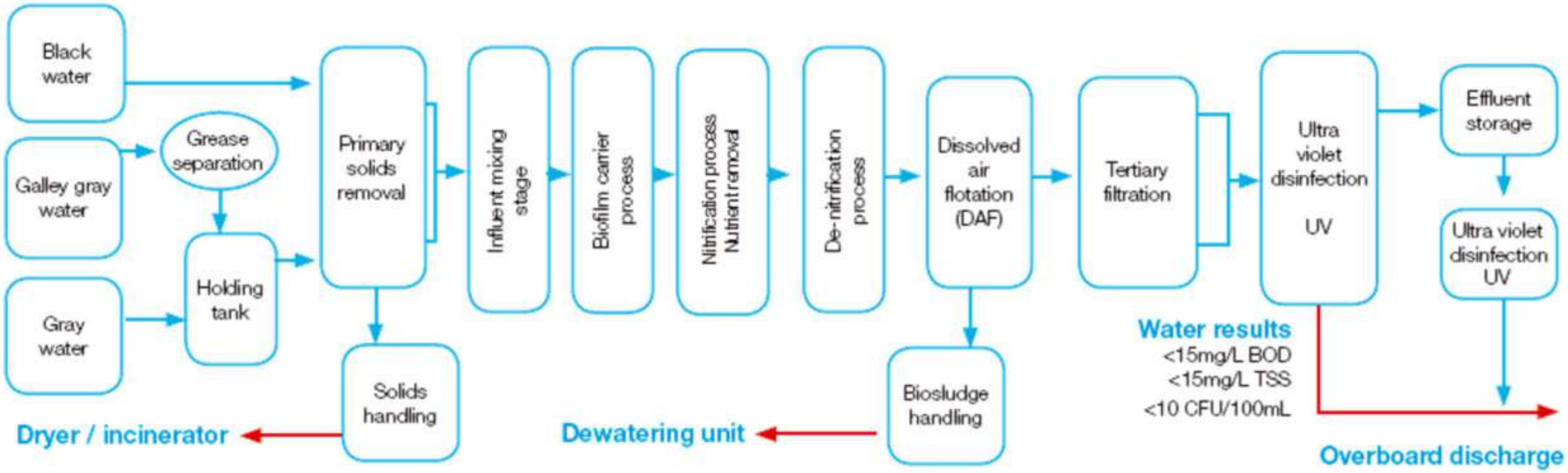
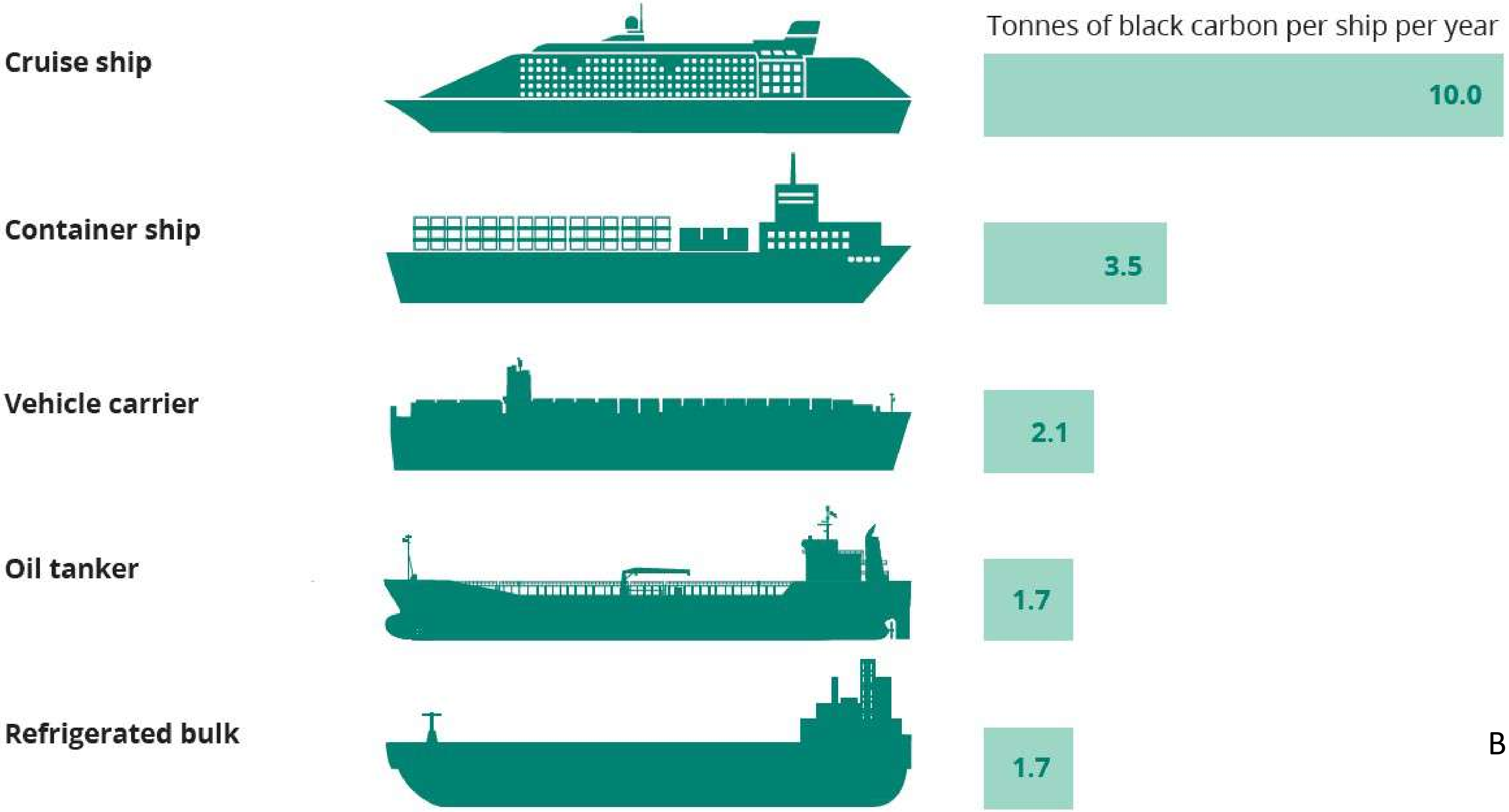
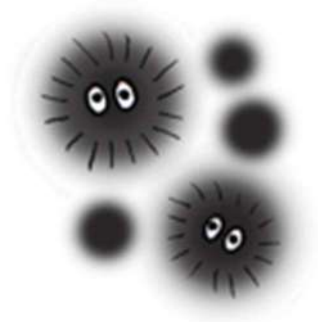


Figure 4.11 Annual global BC emissions by ship type in tonnes



Source: Comer et al. (2017).

European Maritime Transport Environmental Report 2021. EMSA



Black Carbon (Soot)

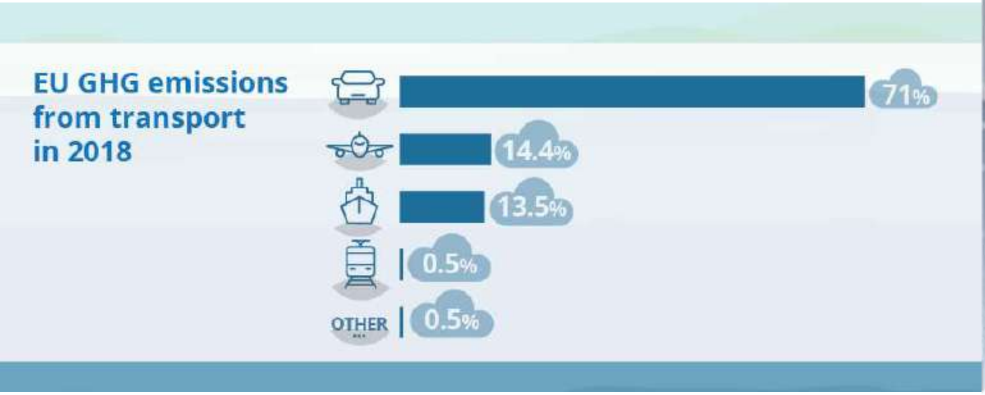
MARITIME TRANSPORT

Co-funded by the Erasmus+ Programme of the European Union

Annex VI of the MARPOL (2005).
Rules to prevent air pollution caused by ships.

Among other issues, restrictions are established for the emissions of sulfur oxides (SOx).

As of January 2020, the maximum sulfur content **in marine fuels has been reduced, from 3.5% to 0.50%** (mass / mass), and a limit of 0.10% of for areas designated as Emission Control Areas (ECAs).



MARITIME TRANSPORT
Scrubber waters

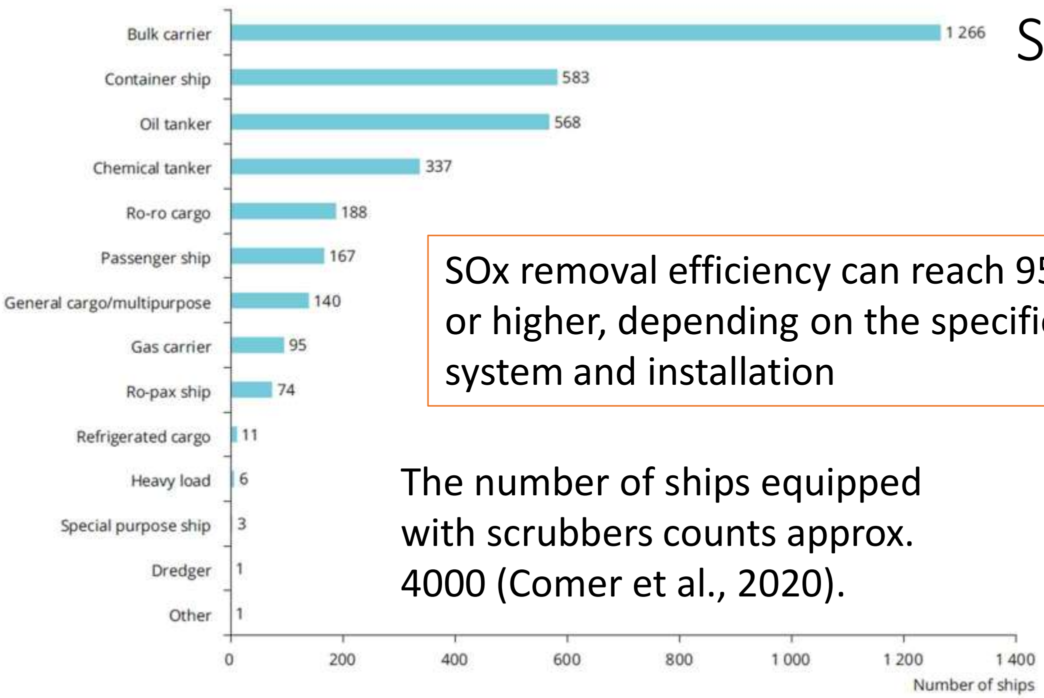
Co-funded by the Erasmus+ Programme of the European Union

There are several options to comply with the restrictions:

- The use of fuels with lower sulfur content
- Installation of **exhaust gas cleaning systems (EGCs),** known as **scrubbers.**

One of the most mature after-treatment technologies and are designed to **remove the SOx matter from the exhaust gases.**

Figure 5.11 **Number of EGCS installations by ship type in 2020**



Source: Compiled from EMSA Services data.

SOx removal efficiency can reach 95 % or higher, depending on the specific system and installation

The number of ships equipped with scrubbers counts approx. 4000 (Comer et al., 2020).

$$SO_2 + H_2O \rightarrow H_2SO_3 \qquad SO_3 + H_2O \rightarrow H_2SO_4$$

$$H_2SO_3 \rightleftharpoons H^+ + HSO_3^- \rightleftharpoons 2H^+ + SO_3^{2-}$$

$$SO_3^{2-} + \frac{1}{2} O_2^- \rightarrow SO_4^{2-}$$

$$H_2SO_4 \rightleftharpoons H^+ + HSO_4^- \rightleftharpoons 2H^+ + SO_4^{2-}$$

· *Comer, B., 2020. ICCT Consult. REPORT, November 2020.*
· *Gregory, D. and Confuorto, N., 2012, Exhaust Gas Cleaning Systems Association, London.*
· *European Maritime Transport Environmental Report 2021. EMSA*

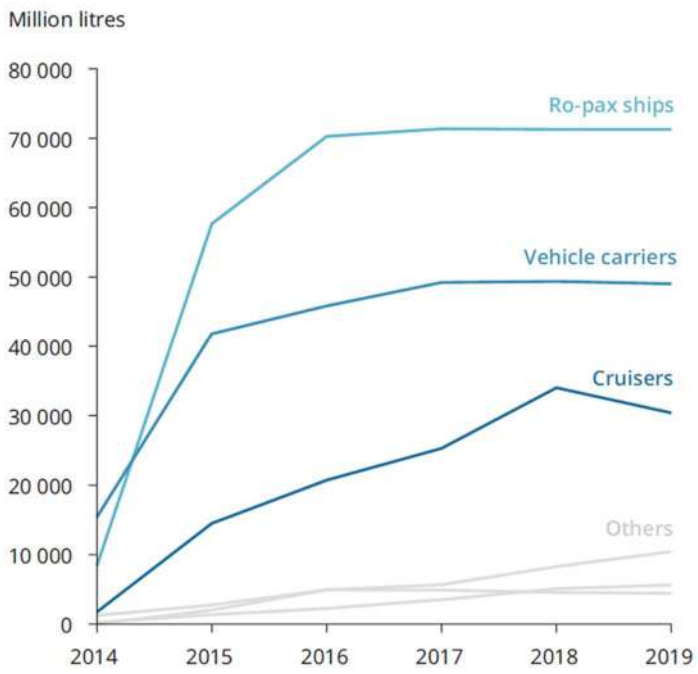
MARITIME TRANSPORT
Scrubber waters

Co-funded by the Erasmus+ Programme of the European Union

Wet systems use sea or freshwater or both for the removal of air pollutants. Depending on the operation mode:

OPEN

Figure 4.18 **Open-loop scrubber (EGCS) estimated water discharges**



Source: STEAM (2021).

· *European Maritime Transport Environmental Report 2021. EMSA*

Water is taken from the sea, used for exhaust gas cleaning, then treated as appropriate and discharged back to the sea

*Typically around 45 m^3 seawater per MWh of combustion unit power if 2.7 % sulphur fuel is consumed).

CLOSED

Wash water is then recirculated (a small quantity of the wash water is bled off to a treatment plant before being discharged to sea) (Gregory and Confuorto, 2012).
Treatment with alkaline chemical such as sodium hydroxide for neutralisation and exhaust gas cleaning.

$$NaOH + H_2O \rightarrow Na^+ + OH^- + H_2O$$

Hydroxide ions will neutralise the surplus acidity:

*Under EU rules, only ships equipped with EGCSs operating in closed mode are allowed to use fuel with a very high sulphur content of more than 3.50 % m/m.

Co-funded by the
Erasmus+ Programme
of the European Union

Scrubber waters

· Seawater is continuously pumped from the surrounding area from the ship for cleaning the exhaust gases.

· **Alkalinity:** the effectiveness of an open loop scrubber depends strongly on the chemistry of the water in which the ship is operating.

$$Na_2CO_3 + H_2SO_4 \rightarrow Na_2SO_4 + H_2O + CO_2$$

· Brackish water and freshwater are not the best option.

· Washwater is collected → Hydrocyclone

· Washwater is discharge and sludge is stored.

Danish Ministry Env. Assessment of possible impacts of scrubber water discharges on the marine environment. Environmental Project No. 1431, 2012

Open loop system

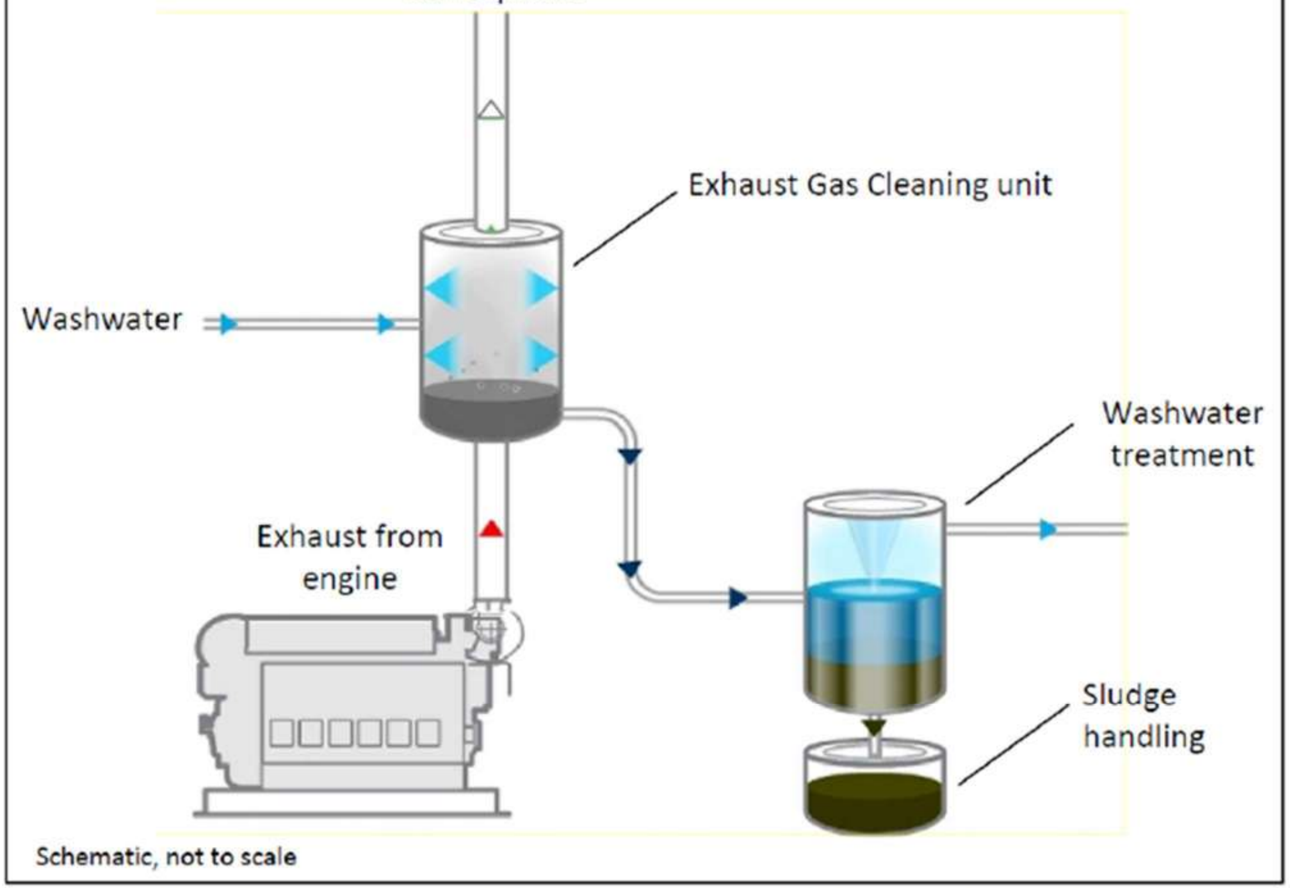


FIGURE 3-1 OPEN LOOP SEAWATER SCRUBBER (COURTESY GREGORY ET AL. 2010)

MARITIME TRANSPORT
Scrubber waters

Co-funded by the Erasmus+ Programme of the European Union

· Water is recirculated.

· **Chemical addition:** NaOH, as scrubbing media to convert the SOx into sodium sulfate.

· Restoration of the alkalinity, and then reused in scrubbing process.

· Purge water is necessary → Bleed-off

· Scrubbing process is independent from the water in which the ship is sailing and then the operation is more stable and efficient.

· More complex systems

Danish Ministry Env. Assessment of possible impacts of scrubber water discharges on the marine environment. Environmental Project No. 1431, 2012

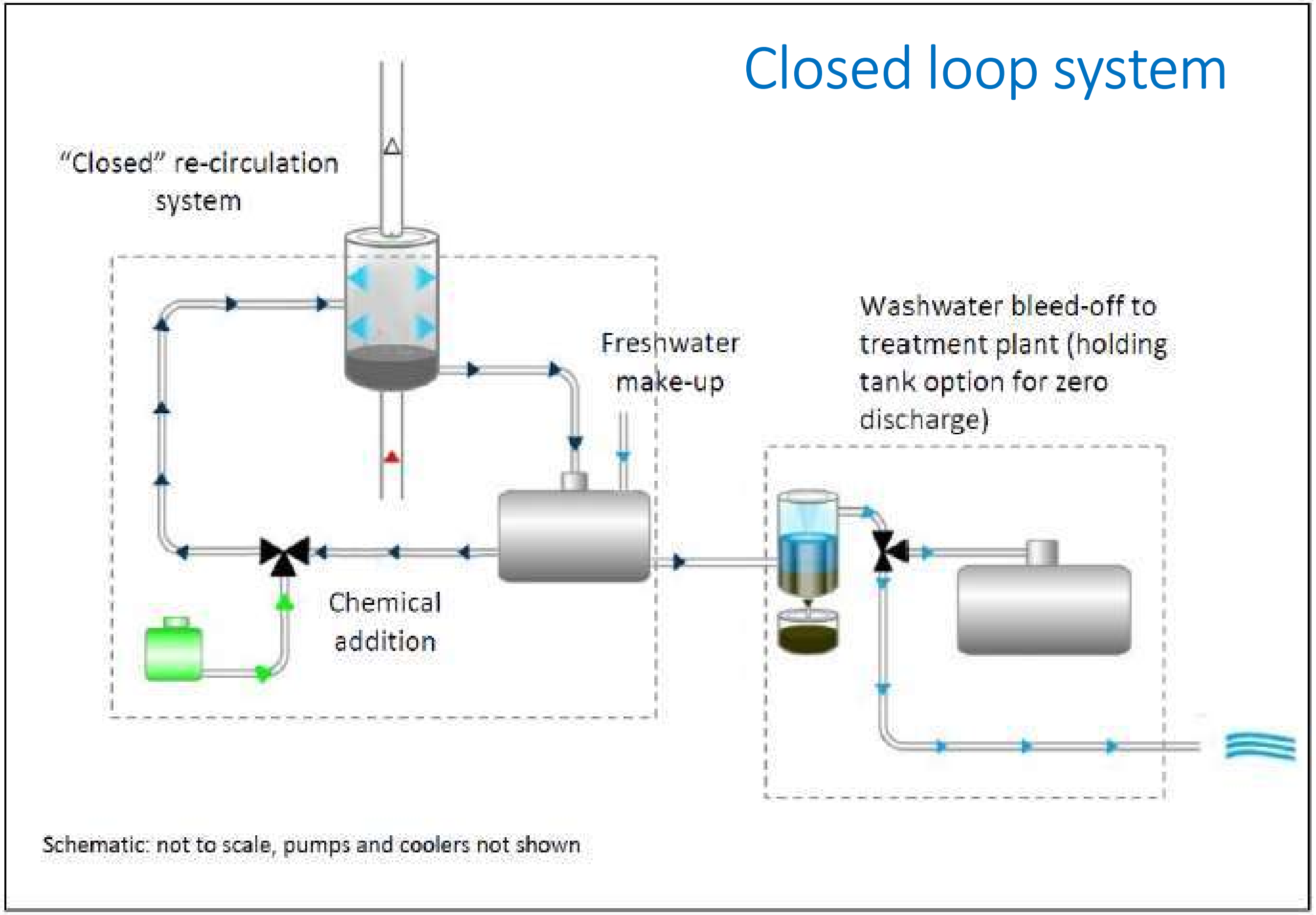
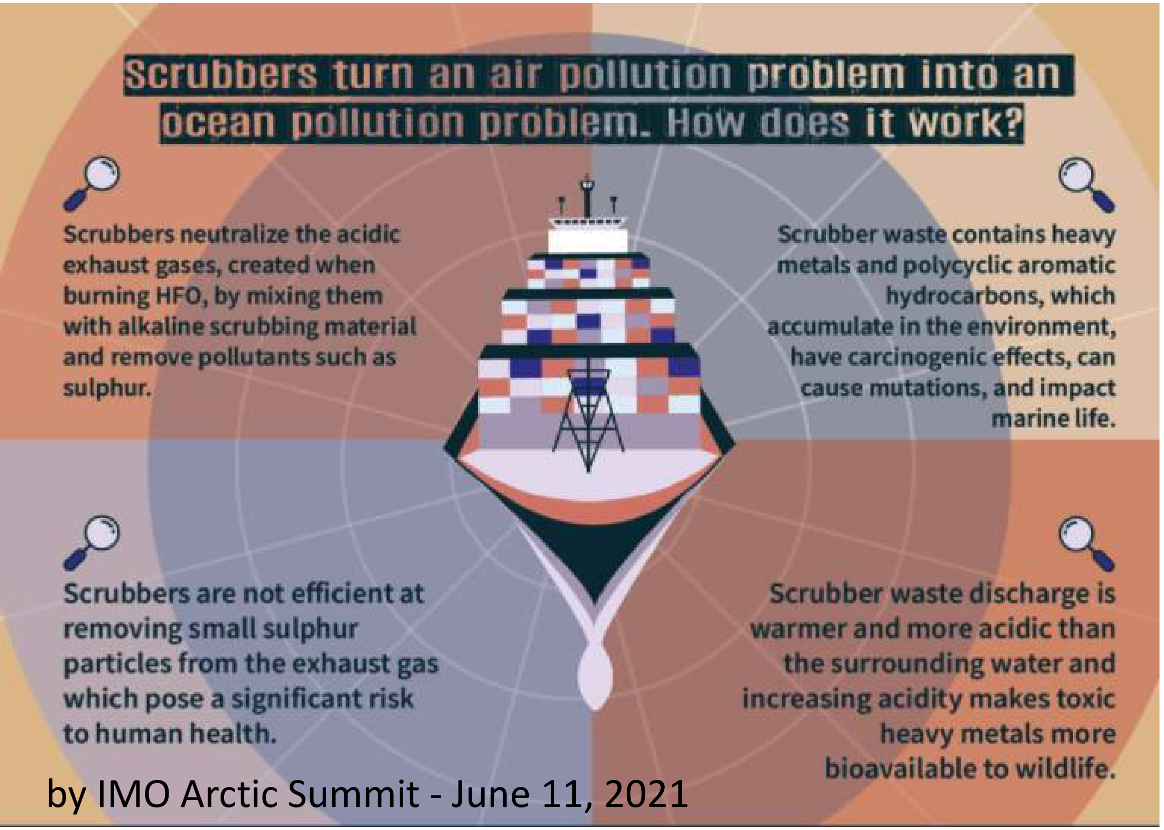


FIGURE 3-2 CLOSED LOOP SCRUBBER (COURTESY GREGORY ET AL. 2010)

MARITIME TRANSPORT
Scrubber waters

MEP&M · UCA Universidad de Cádiz · Co-funded by the Erasmus+ Programme of the European Union

As EGCSs use water to remove the pollutants, effective controls may be needed to minimize **the potential negative effects,** if any, on the marine environment caused by the resulting **overboard discharges** (e.g. discharge water, bleed-off).



by IMO Arctic Summit - June 11, 2021

Concerns about the negative effects include:

· **Acidification** (change in pH values)

· Possible releases of **heavy metals**

· Polycyclic aromatic hydrocarbons (**PAHs**).

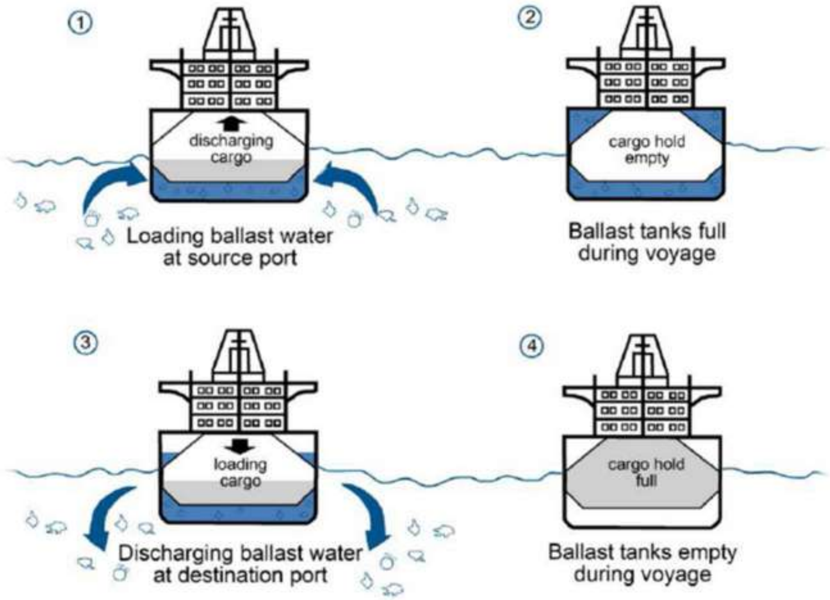
IMO, May 2019

Expected to be completed at IMO level by 2022.

Evaluation and harmonisation of rules and guidance on the discharge of water from EGCS into the aquatic environment

MARITIME TRANSPORT
Ballast water

Co-funded by the Erasmus+ Programme of the European Union



Among the mainly water streams generated on vessels, appears:

Ballast Water as emerging challenge

Ballast water is needed on oceangoing vessels to ensure ship stability and buoyancy

Source: bwbearthenviro2011

Source: Maersk group

MARITIME TRANSPORT
Ballast water

BALLAST DEPENDENCE

	Vessel Type	Ballast tank	Flow rate, m^3 /h
High Ballast Dependent Vessels	Bulk carriers	18 000 – 65 000	1 300 - 3 000
	Tankers	6 500 – 95 000	1 100 – 5 800
Low Ballast Dependent Vessels	Containerships	3 000 – 20 000	250 – 750
	Other vessels	3 000 – 11 000	250 – 600

GloBallast.

Figure 4.36 **Estimations of ballast water discharges in EU waters by ship type**

Source: STEAM (2021).

Co-funded by the Erasmus+ Programme of the European Union

Ballast Water as emerging challenge

Source: responseables.eu

Ballast water is needed on oceangoing vessels to ensure ship stability and buoyancy

Source: bwbearthenviro2011

MARITIME TRANSPORT
Ballast water

MEP&M | UCA Universidad de Cádiz | Co-funded by the Erasmus+ Programme of the European Union

WITHIN FOUR MAJOR GLOBAL THREATS TO THE OCEANS

Invasive aquatic species involve a global challenge and one of the **most severe pollution problem** facing the world´s oceans

Generates huge impacts on **Environment, Economy**, and **Public Health**

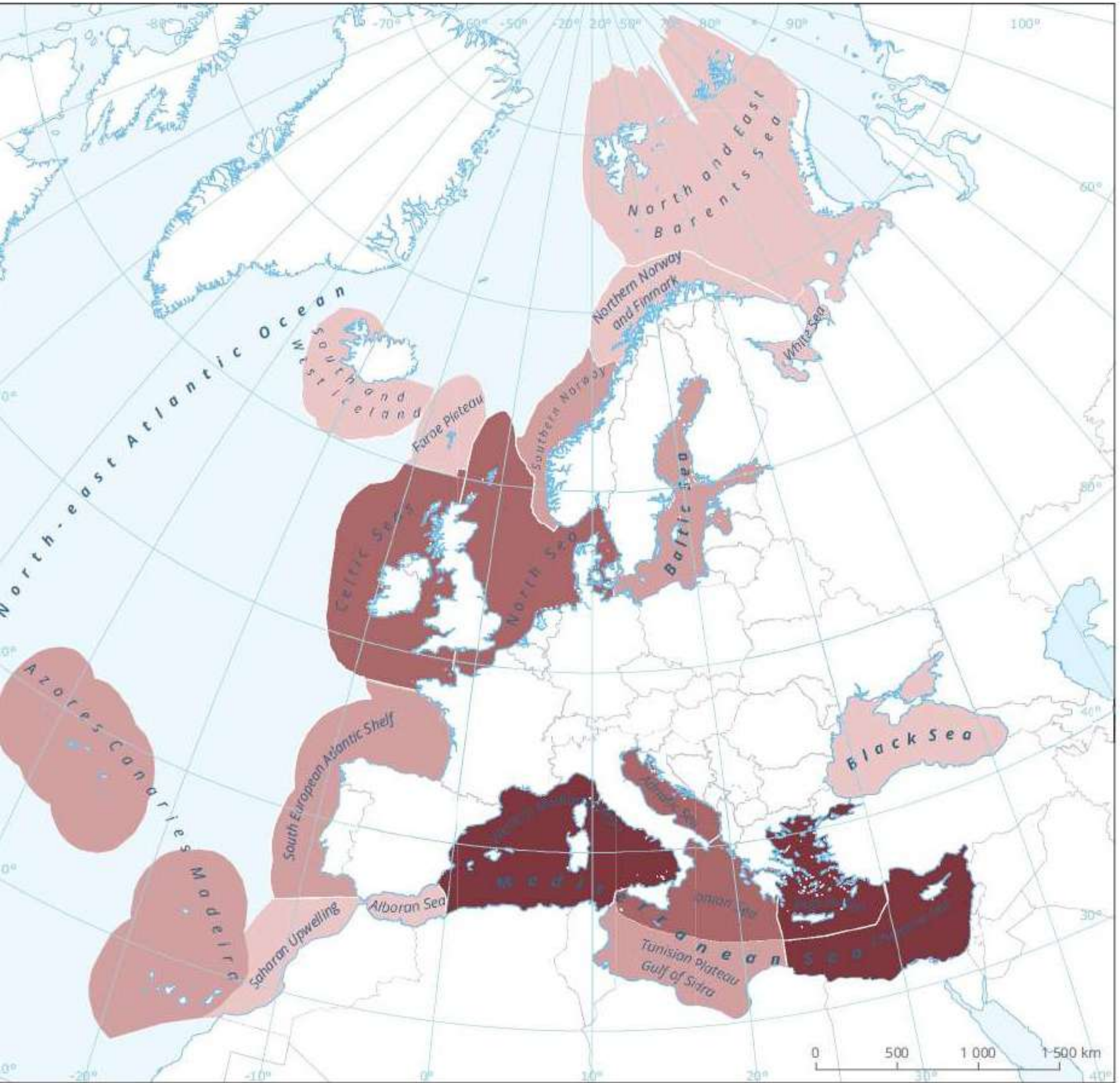
Up to **five billion** tonnes of ballast water is transferred throughout the world annually

Shipping is the main pathway for alien species introduction

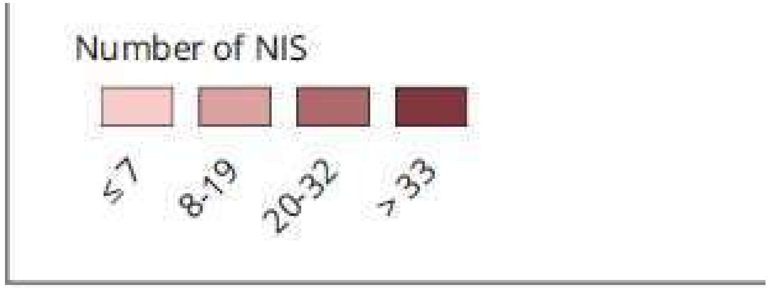
Transfer of
10,000
unwanted species daily

Source: hcmr.gr

Drake et al. (2007)
Endresen et al. (2013)
Werschkun et al. (2014)



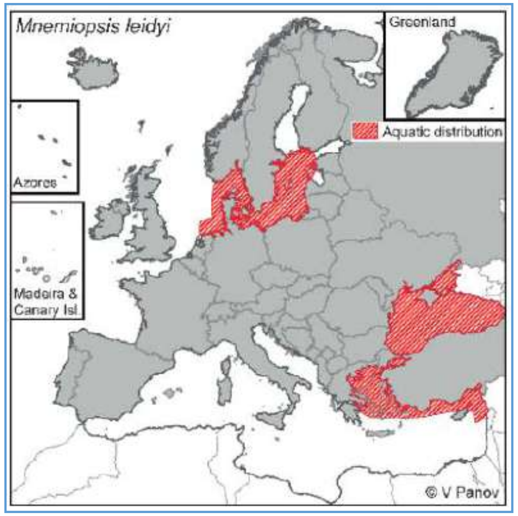
NIS of high impact introduced by shipping



Source: EASIN Hulme framework (EASIN, 2021).

MARITIME TRANSPORT
Ballast water

MEP&M | UCA Universidad de Cádiz | Co-funded by the Erasmus+ Programme of the European Union



Dreissena polymorpha

Eriocher sinensis

Mnemiopsis leydyi

DAISIE (2009)

MARITIME TRANSPORT
Ballast water

MEP&M | UCA Universidad de Cádiz | Co-funded by the Erasmus+ Programme of the European Union

IMO INTERNATIONAL MARITIME ORGANIZATION

International Convention for the Control and Management of Ships' Ballast Water and Sediments

12 months after **30 states** have ratified it, and they represent at least **35%** of world merchant shipping tonnage

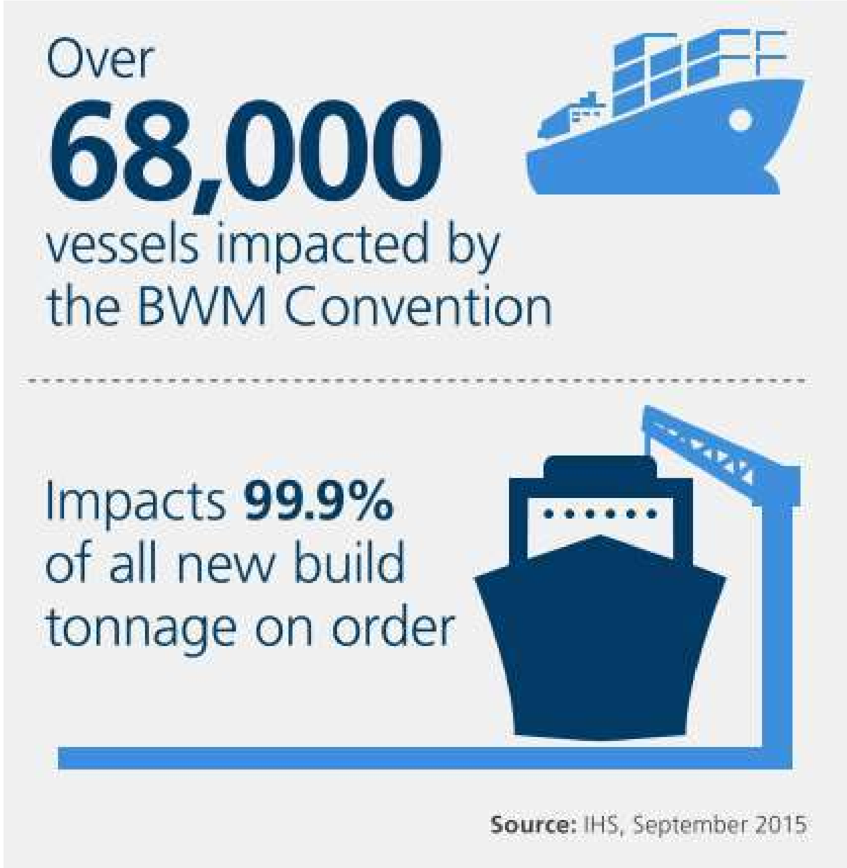
All cargo ships must have a system for treating ballast water that meets a number of parameters set out in Rule D2

BWMC was adopted in 2004 and entered into force from September-2017

As of September 2021, 86 countries that supposes the **91.19%** of the world's merchant fleet tonnage

The USCG's final rule was published on March 23, 2012 in the Federal Register

USCG United States Coast Guard national requirements are already in force

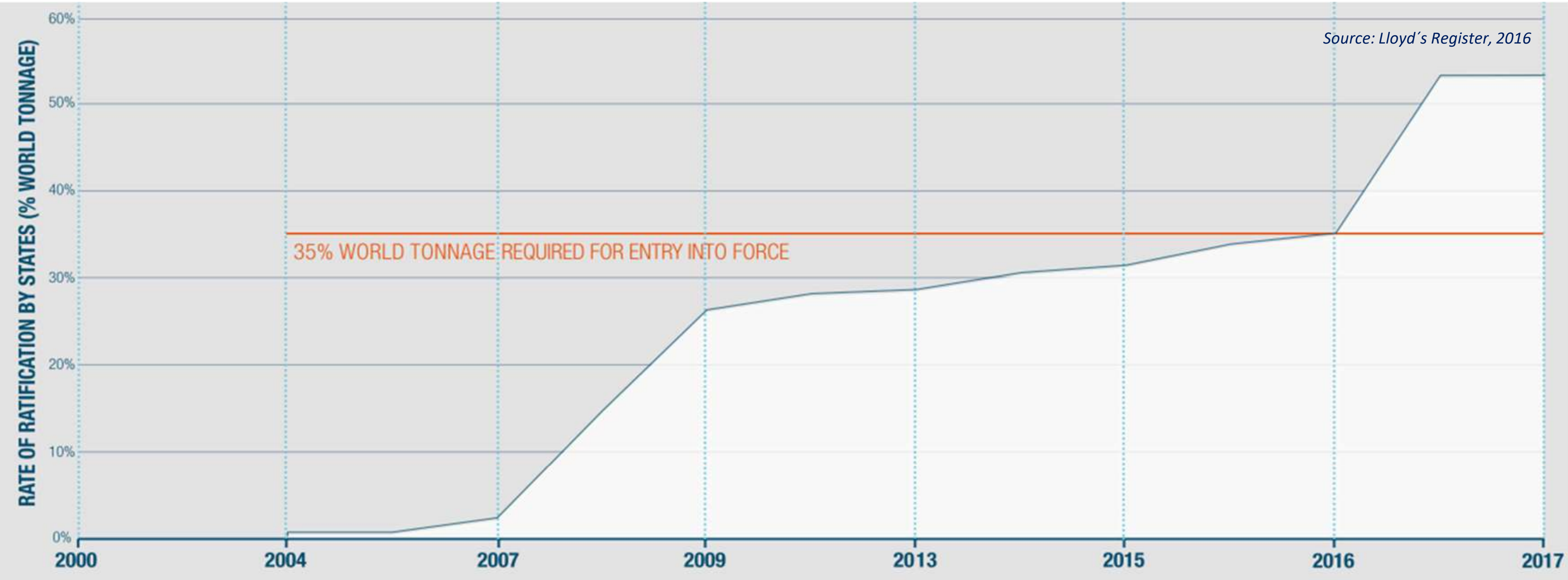


MARITIME TRANSPORT
Ballast water

MEP&M | UCA Universidad de Cádiz | Co-funded by the Erasmus+ Programme of the European Union

IMO INTERNATIONAL MARITIME ORGANIZATION

International Convention for the Control and Management of Ships' Ballast Water and Sediments



Co-funded by the Erasmus+ Programme of the European Union

International Convention for the Control and Management of Ships' Ballast Water and Sediments

Standard	Element	Condition
D-1 Standard — Ballast water exchange	Physical	At least 95 % volumetric exchange of water in the ballast tanks. This is equal to pumping through the volume of each ballast water tank three times
	Geographical	Exchange should occur at least 200 nm from nearest land and in water 200 m deep. If not possible, then exchange should take place as far from the nearest land as possible, and at least 50 nm from the shoreline in 200 m depth of water

Regulation D-2 Ballast Water Performance Standard

Indicator microbes	Limit Discharge
Vibrio cholerae	1 UFC/100 mL
Escherichia coli	250 UFC/100 mL
Enterococci	100 UFC/100 mL
Standard organisms	**Limit discharge**
Organisms greater than or equal to 50 µm	10 viable organisms/m^3
Organisms 10 - 50 µm	10 viable organisms/mL

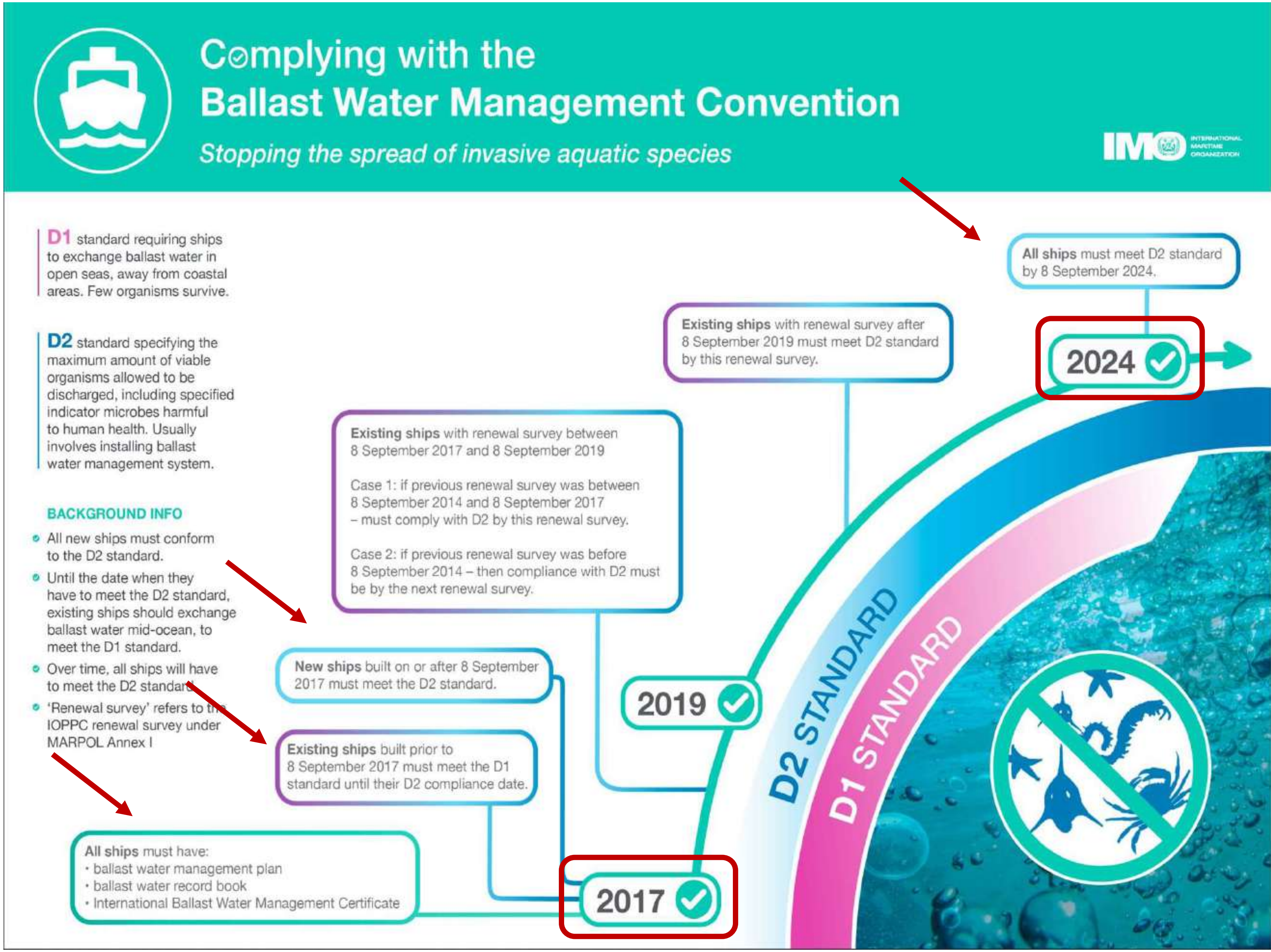
USCG
United States Coast Guard national requirements are already in force

MARITIME TRANSPORT

Ballast water

Amendments to the Convention

BWM Code



MARITIME TRANSPORT
Ballast water

It is necessary to develop treatment technologies that are efficient in both freshwater and saltwater

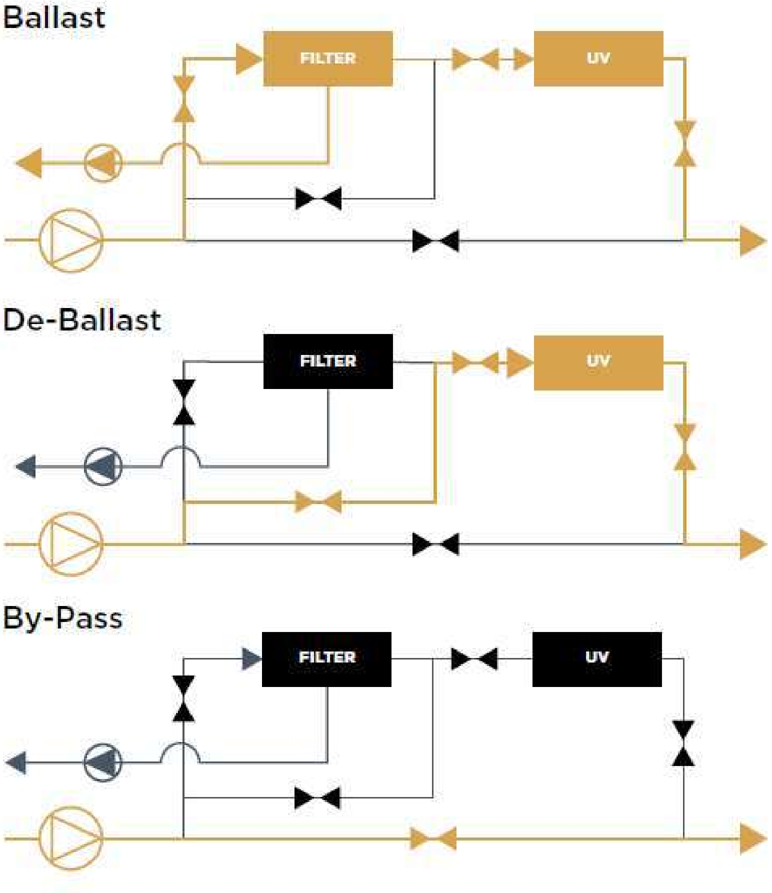


Figure 2: Treatment of Ballast Water DESMI

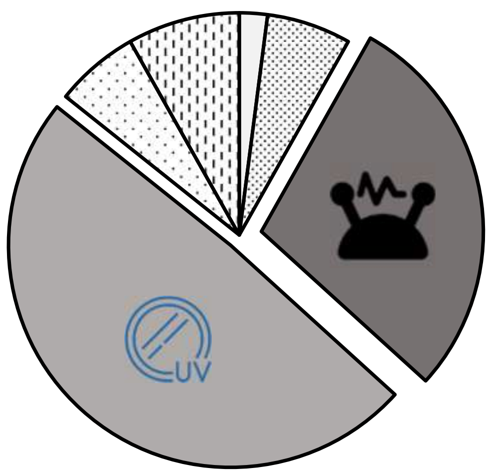
Physical separation

UV treatment (≈ 48%)
Chemical disinfection (≈36%)

Disinfection phase

Chemical treatment:
- Biocides:
    - Chlorine Dioxide
    - SeaKleen
    - Peracetic Acid
- Electrochlorination
- Ozone

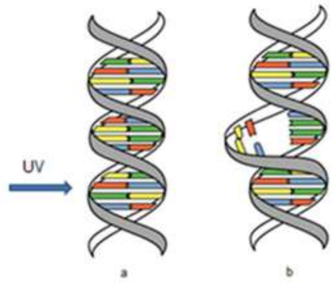
Physical treatment:
- UV irradiation
- Deoxygenation
- Ultrasound



Hess-Erga, O.-K. et al., 2019. Sci. Total Environ. 657, 704–716.

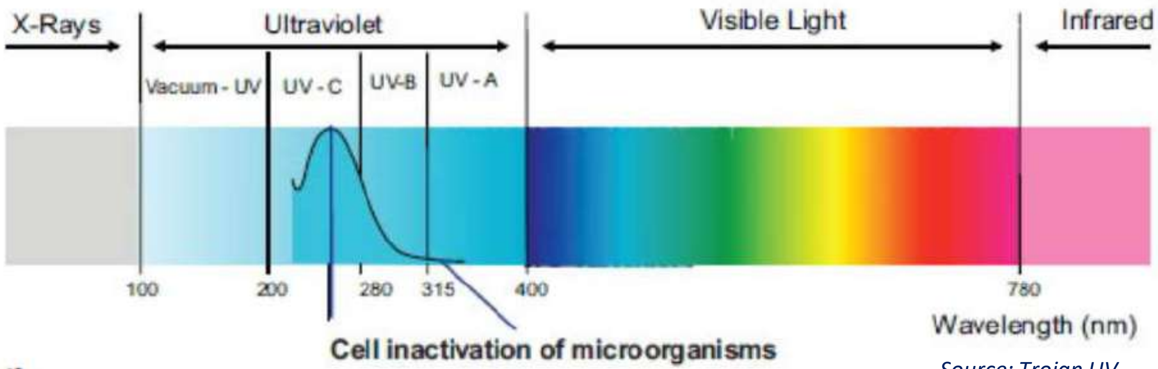
DISINFECTION TECHNOLOGY

UV-light "can be considered as a traceless and green reagent"
Su et al. (2014)



UV-radiation

UV light is transferred to genetic material.
Inhibit normal DNA replication and therefore lead to the inactivation of microorganisms



Source: Trojan UV

UV-C most germicidal wavelength, with DNA damage

UV-B oxidative stress and DNA damage

UV-A oxidative damage to lipids and proteins

The most effective spectral region for inactivation occurs at a wavelength of 254 nm (UV-C), since DNA exposed to this energy has a maximum absorption, and therefore inactivation

MAIN ADVANTAGE: not generates by- products

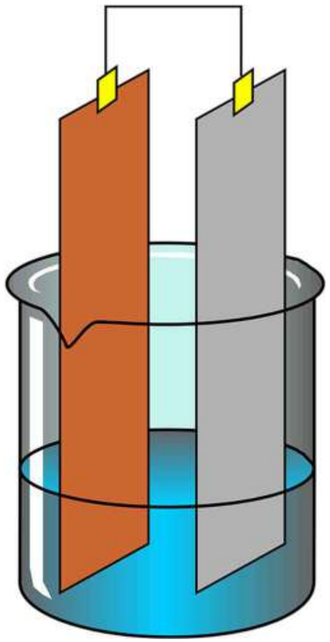
Hijnen, E.F. et al. (2006)
Nebot, E. et al. (2007)
Santos, et al. 2013, 195, 63–74, doi:10.1007/s00203-012-0847-5.

Electrochemical Oxidation Processes

Disinfection mechanisms → **Chlorine generation** $2Cl^- \rightarrow Cl_2 + 2e^-$

Electrical shock

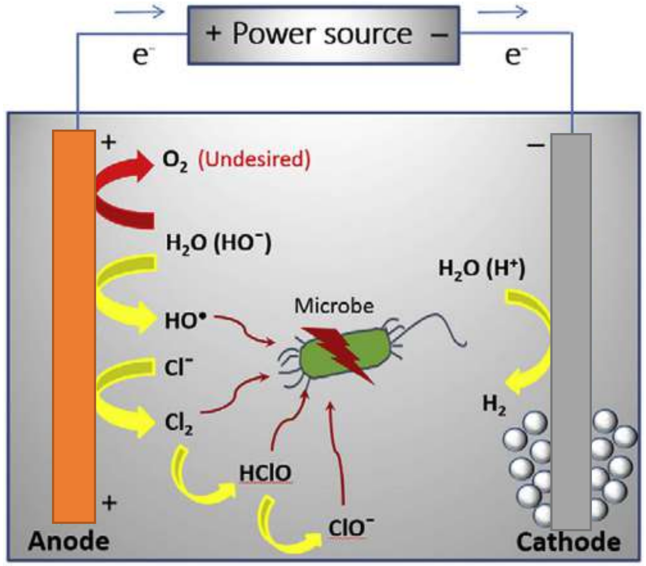
Hydroxyl radical generation $H_2O \rightarrow \bullet OH + H^+ + e^-$



Chaplin, (2014)
García-Segura et al. (2017)

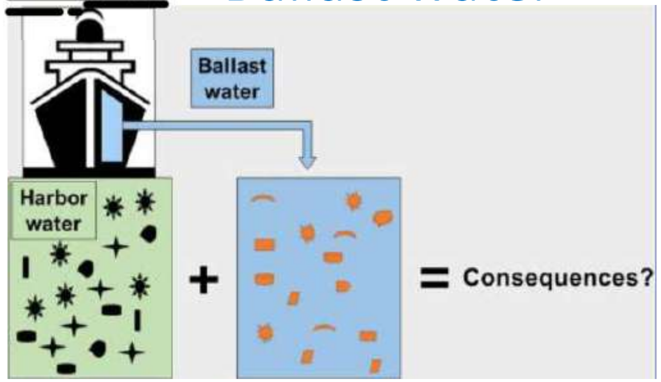
Electrode material

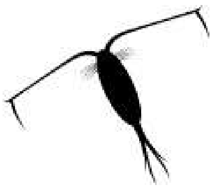
With **non-active electrodes** (BDD), higher efficiencies in the electro-generation of Reactive Oxygen Species (ROS) can be obtained



Source: Ghasemian et al. 2017

MARITIME TRANSPORT
Ballast water

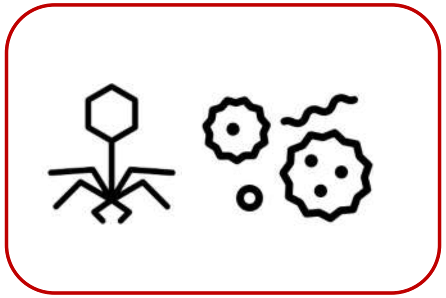




> 50 µm
(Zooplankton)

10-50 µm
(Phytoplankton)

The majority of them can be removed by physical barrier, such as filtration

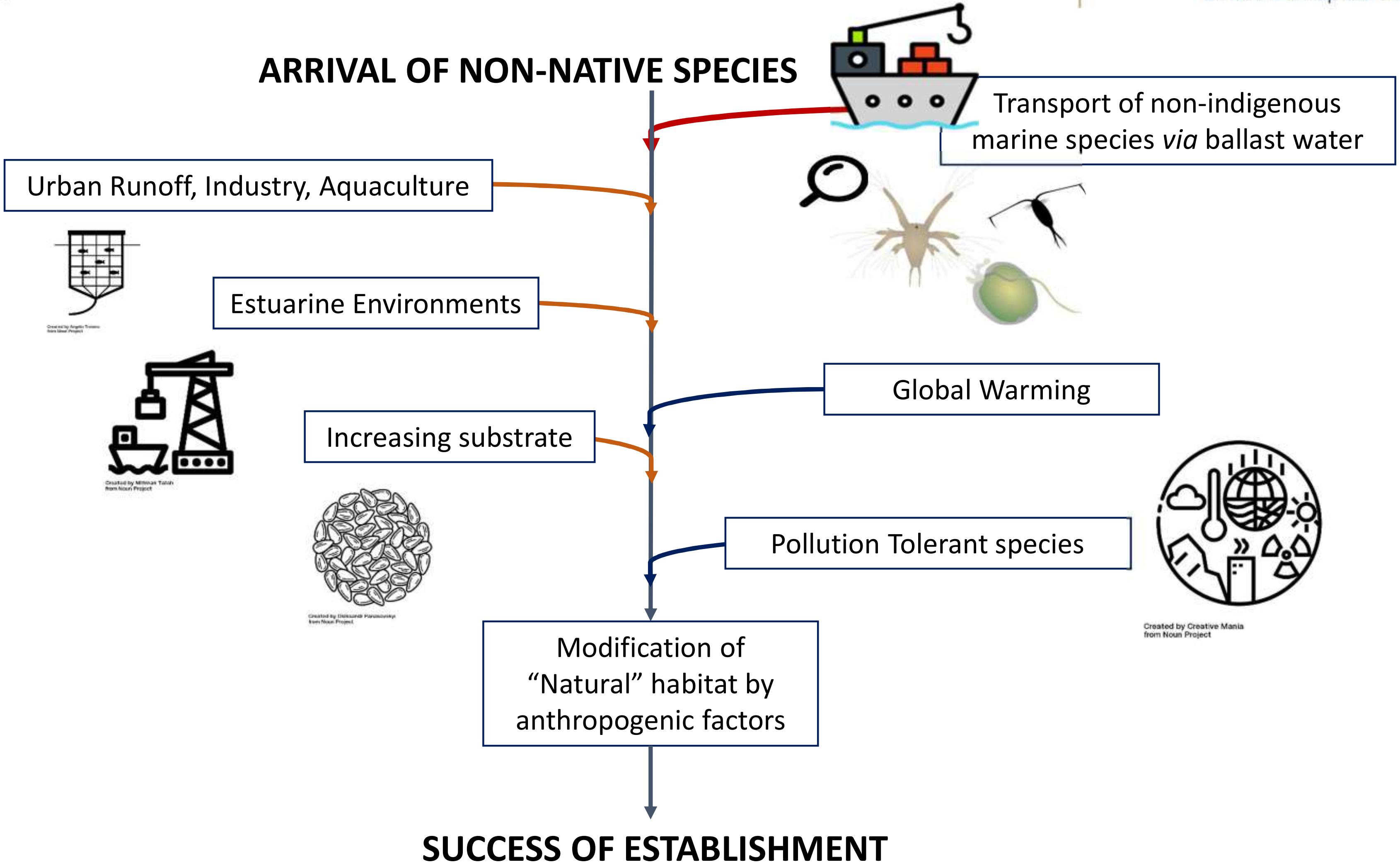


< 10 µm
(Bacteria and Virus)

MEP&M
UCA Universidad de Cádiz
Co-funded by the Erasmus+ Programme of the European Union

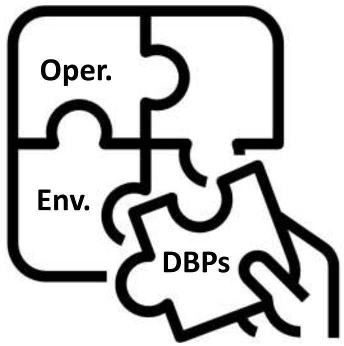
MARITIME TRANSPORT
Ballast water

Co-funded by the Erasmus+ Programme of the European Union



MARITIME TRANSPORT
Ballast water

David, M. et al. 2018. Chemosphere 207, 590–600.



G8, G9 Guideline

Water quality parameters		IMO		
	Salinity (PSU)	28-36	10-20	<1
Organic Matter ($mg \cdot L^{-1}$)	DOM	>1	>5	>5
	POC	>1	>5	>5
	MM	-	-	-
Suspended Solid Material ($mg \cdot L^{-1}$)		>1	>50	>50
Temperature		-	-	-

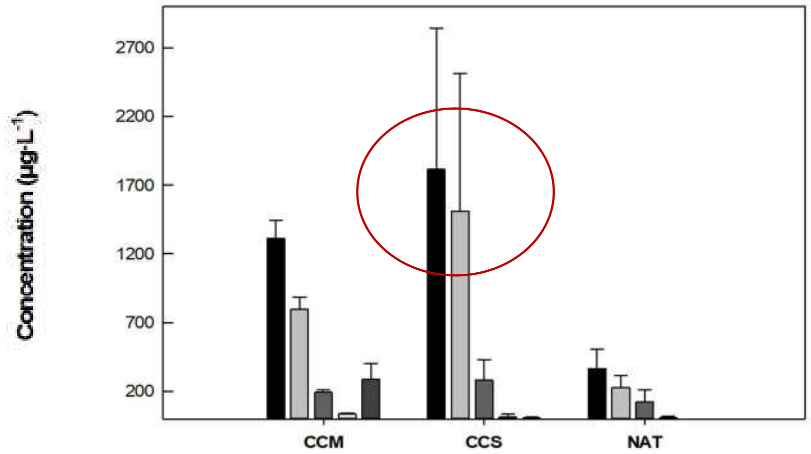
Salinity: Cl^- and Br^- concentrations (~1000 and 672 times higher than FW)

Shah, A.D. et al. 2015. Environ. Sci. Water Res. Technol. 1, 465–480.

Organic Matter augmentation: Wide additives as a source of organic carbon

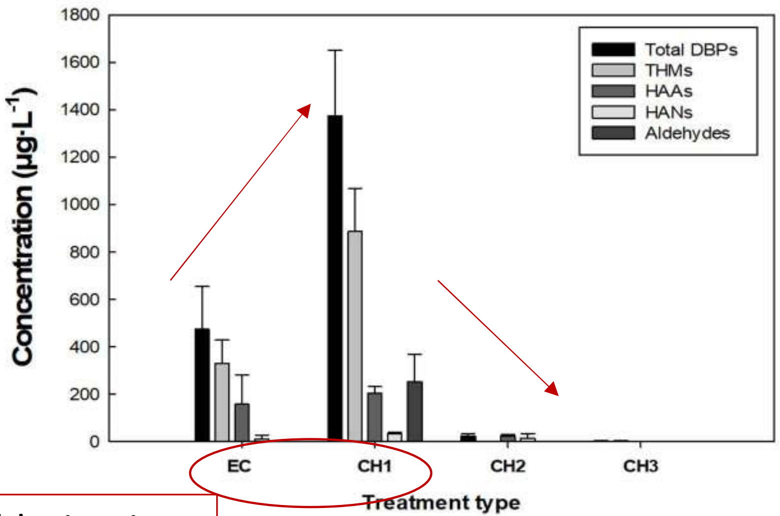
MARITIME TRANSPORT
Ballast water

Co-funded by the Erasmus+ Programme of the European Union

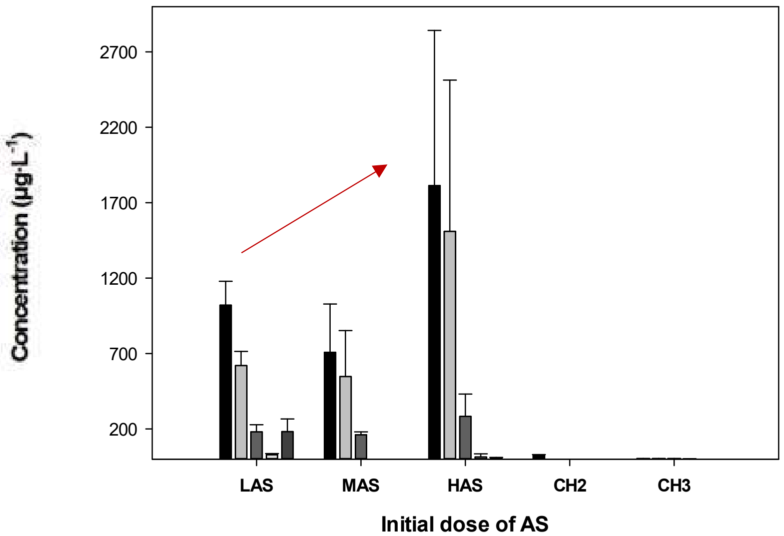


- **Source of Carbon:** Natural Wadden Sea mud (NAT); Commercial clay and methylcellulose (CCM); Commercial clay, citric acid and Humifirst® (CCS)

- **Initial dose of Active Substance:** 5-20 mg $Cl_2 \cdot L^{-1}$ CH2 and CH3 applied a single specific dose of 5 mg $ClO_2 \cdot L^{-1}$ and 150 mg $PACC \cdot L^{-1}$.

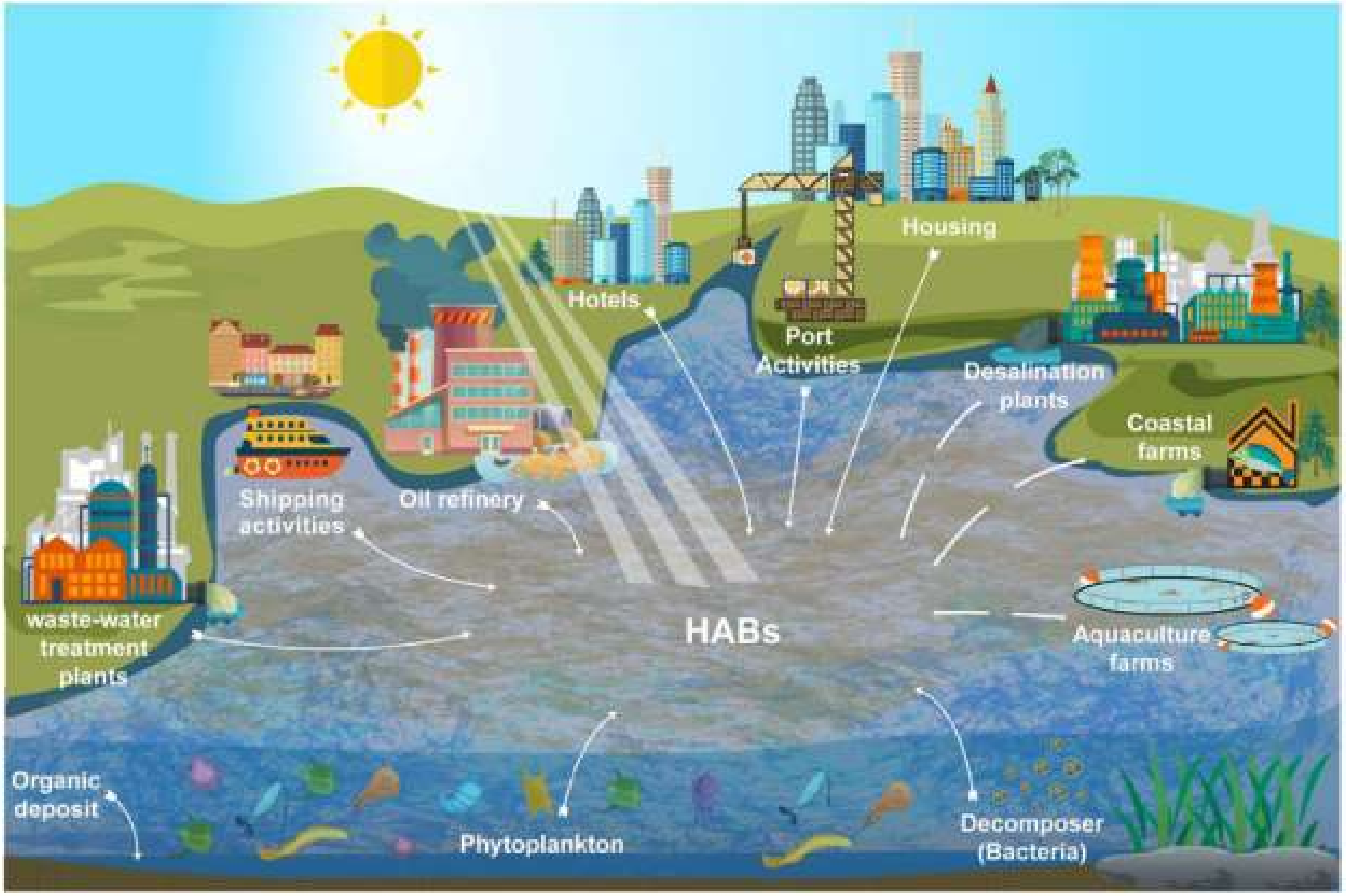


Chlorination



Moreno-Andrés & L. Peperzak. 2019. Chemosphere. 239, 496-505

MEP&M
UCA Universidad de Cádiz
Co-funded by the Erasmus+ Programme of the European Union



Trottet, Crit. Rev. Environ. Sci. Technol. 2021, 1–42

WASTEWATER

MARITIME TRANSPORT

AQUACULTURE FACILITIES

AQUACULTURE

Co-funded by the Erasmus+ Programme of the European Union

Diversity of aquaculture farms:

(i) **Intensity** (extensive, semi-intensive or intensive);

(ii) **Water exchange** (open, semi-closed or closed);

(iii) **Culture structure** (e. g. cages, race- ways or concrete/fiberglass tanks)

(iv) **Farming methods** (mono- or poly-culture).

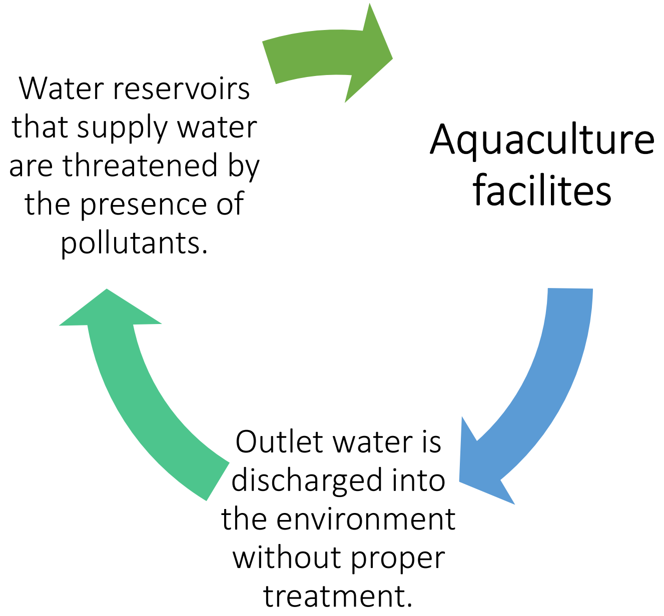
Addition of different substances during production:

Veterinary drugs, disinfectants, and antifoulants are frequently used to improve the survival rates of cultured organisms and to control pathogens (European Commission, 2016).

Tetracyclines, trimethoprim, sulfonamides and phenicols are some of the most commonly used medicines (Leal et al., 2016)

Aquaculture water is a heterogeneous system that varies in the composition and content of each specific substance.

Nitrogen and phosphorus can be excreted by aquatic species and contribute to eutrophication. (Buhmann and Papenbrock, 2013)



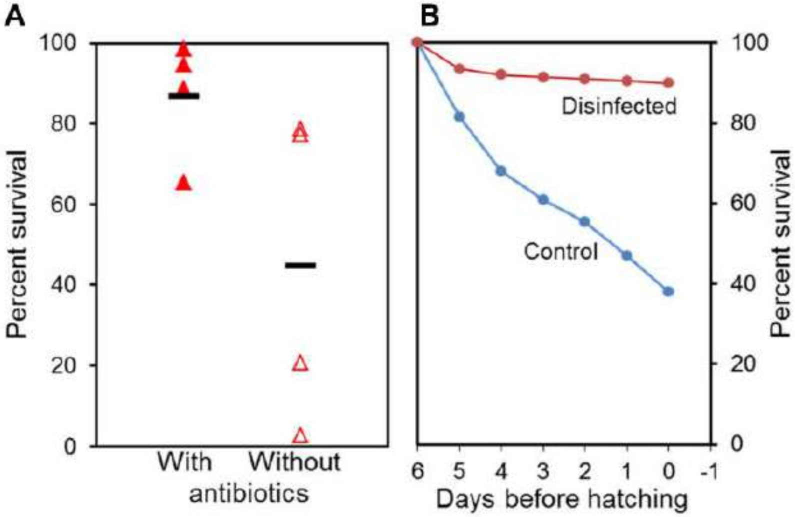
AQUACULTURE

Co-funded by the Erasmus+ Programme of the European Union

Proliferation of undesirable microorganisms, such as pathogenic bacteria.

Aquaculture farms are also considered to be a possible source of MPs in the aquatic environment (Barbosa et al., 2016; Gorito et al., 2021).

Disinfection and **probiotics** are the most studied microbial management methods so far.



Effect of **addition of antibiotics** to yolk sac larvae (A) and **surface disinfection** of eggs (B) on survival of Atlantic halibut. From: *Vadstein et al. 2018. Front. Microbiol. 9, 2730.*

Table 1
Antibiotic use in Norway and Scotland 2006–2008. Quantities are reported in kg of active ingredient. Source: Norwegian Institute of Public Health (2009) and Scottish Environmental Protection Agency.

Antimicrobial	Country	2006	2007	2008
Oxytetracycline	Norway	0	19	23
	Scotland	5282	1532	75.4
Florfenicol	Norway	302	139	166
	Scotland	32	21	9
Flumequin	Norway	7	18	1
Amoxycillin	Scotland	55.2	0	0
Oxolinic acid	Norway	1119	406	681
Lincomycin/streptomycin (1:2)	Norway	50	67	70

Table 2
Total antibiotic use (kg active ingredient) in Canada and Chile.

Total antibiotics	2006	2007	2008*
Canada[a]	13,522	21,330	5093
Chile	NA	385,600	325,600

[a]Data for the provinces of British Columbia and New Brunswick or for *British Columbia only. Data are not available for other Canadian provinces.

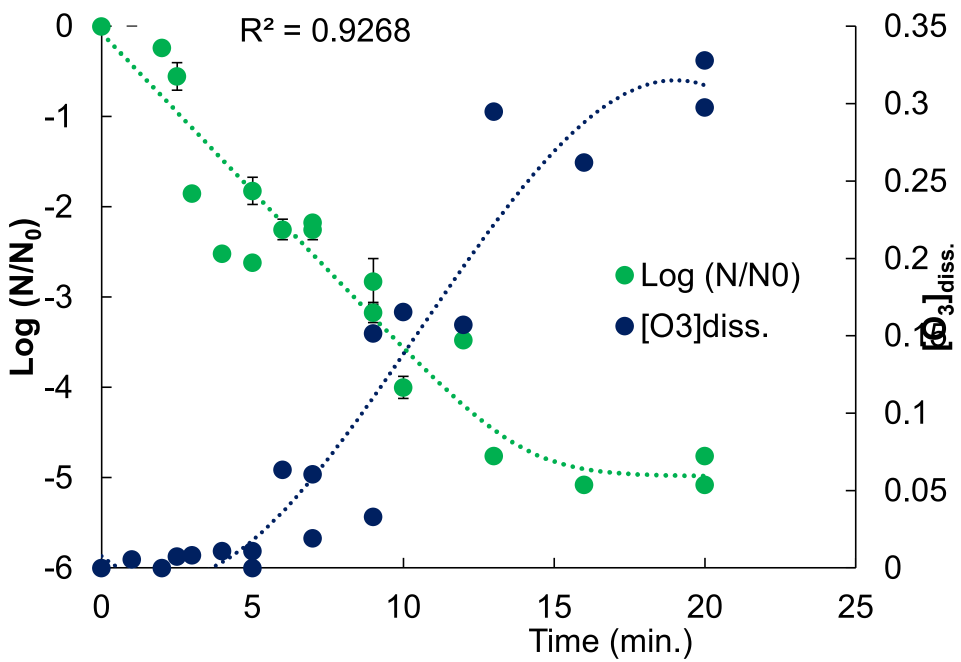
AQUACULTURE

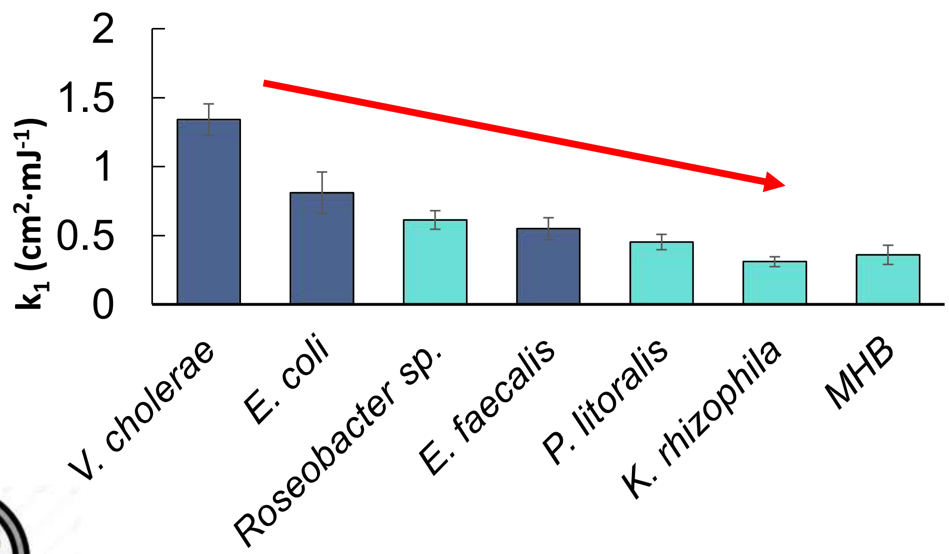
Co-funded by the Erasmus+ Programme of the European Union

UV-irradiation and ozonation are two common methods used for disinfection of intake water.

Ozonation, however, is in most cases motivated by improvement of the physicochemical water quality rather than disinfection.

The water treatment may include UV-irradiation to reduce the abundance of bacteria.





Attramadal, et al. 2012. Aquaculture 330–333, 121–129. & Aquac. Eng. 46, 27–39.
Summerfelt, S.T., 2003. Aquac. Eng. 28, 21–36.
Tango, M.S., Gagnon, G.A., 2003. Aquac. Eng. 29, 125–137.
Moreno-Andrés. et al. J. Environ. Chem. Eng. 2020, 8, 104335,
Moreno-Andrés et al. Sci. Pollut. Res. 2018, 25, 27693–27703.

AQUACULTURE

Co-funded by the Erasmus+ Programme of the European Union

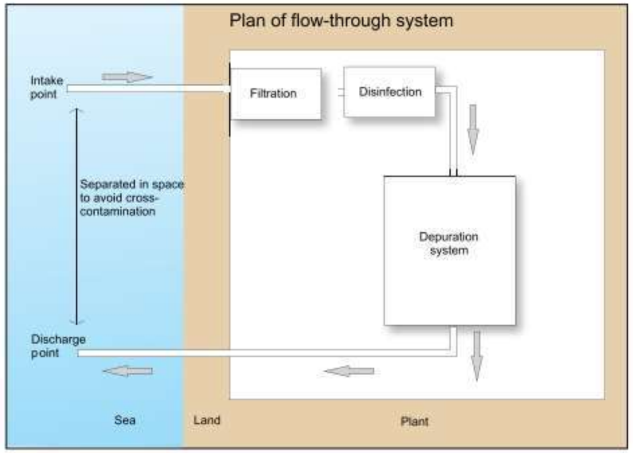


Figure 5.7: Flow of seawater in a flow-through system

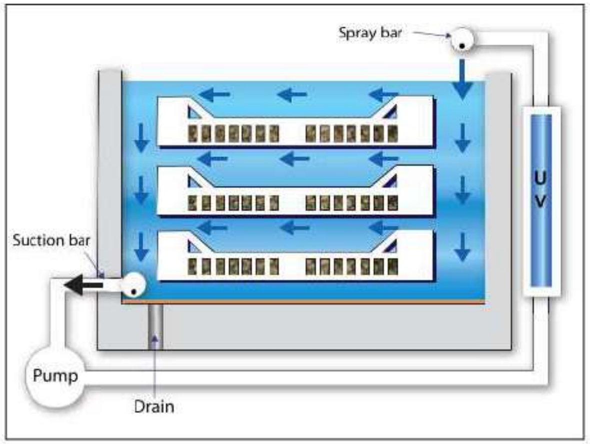


Figure 3.1: Diagram of seawater flow through a loaded tank in a recirculation system

Table 6.1: Comparison of three water disinfection systems

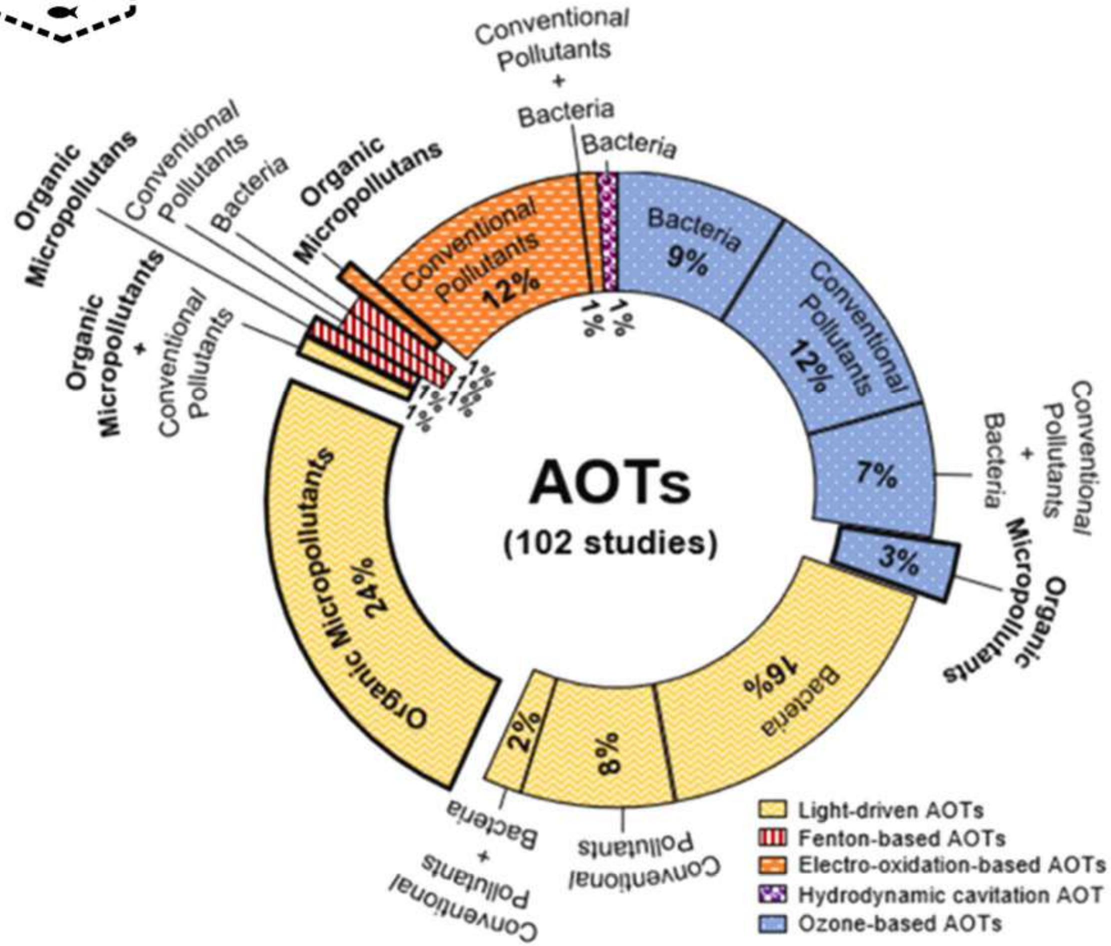
Operation/condition	Ultraviolet light	Chlorine/chlorine compound	Ozone
Capital costs	Low	Medium	High
Operating costs	Lowest	Low	High
Installation	Simple	Complex	Complex
Ease of maintenance	Easy	Moderate	Difficult
Cost of maintenance	Low	Medium	High
Performance	Excellent	Possible growth	Unreliable
Source water clarity	High	Low	Medium
Virucidal effect	Good	Poor	Good
Personnel hazards	Medium (eyes, skin)	High	Medium (oxidant)
Toxic chemical	No	Yes	Yes
Residual effect	No	Yes	Some
Effect on water	None	Trialomethanes	Toxic by-products
Operating problems	Low	Medium	High
Contact time (mm)	1–5 sec	30–60 mm	10–20 mm
Effect on shellfish	None	Irritant	Oxidant

Source: Zinnbauer, *Pharmaceutical Engineering* March-April, 1985.

FAO. Bivalve depuration: fundamental and practical aspects. 2008; ISBN 978-92-5-106006-3.
Martinez-Albores et al. Foods 2020, Vol. 9, Page 129.

AQUACULTURE

Co-funded by the Erasmus+ Programme of the European Union



Additional Information:
Light-driven AOTs include UV, UV/H_2O_2, and UV photocatalytic processes
Fenton-based AOTs include Fenton, photo-Fenton and Fenton-like catalysis processes
Electro-oxidation-based AOTs include electro-oxidation, electrocatalysis, UV/electro-oxidation, electro-Fenton processes
Ozone-based AOTs include O_3, O_3/H_2O_2, O_3/H_2O_2/UV, O_3 catalytic and O_3 photocatalytic processes

Target pollutants:

Bacteria
Organic micropollutants
Conventional Pollutants

the most representative AOTs,
UV (51 %)
Ozone-based (31 %)

followed by

electro- oxidation (14 %),
Fenton (3 %)
hydrodynamic cavitation (1 %)

LAND and SHIPPING-based effluents as sources of marine pollution: Technologies for its minimization.

UCA Universidad de Cádiz

MEP&M

Co-funded by the Erasmus+ Programme of the European Union

KEY ASPECTS

POLICIES

- Marine Pollution is adressed in recent policies: SDGs / Ocean Decade

LEGAL REQUIREMENTS

- European Directives and IMO Conventions are further developed; e.g. Watch Lists, Ballast Water Convention, Scrubber issues

STRATEGIES AND TECHNOLOGICAL DEVELOPMENT

- Newly and adapted technological strategies to reach these requirements

¡GRACIAS! Thank you

Faleminderit Hvala.

Javier Moreno Andrés
javier.moreno@uca.es

Dpt. of Environmental Technologies
INMAR- Marine Research Institute
CEI·MAR- International Campus of Excellence of the Sea
University of Cadiz. Faculty of Sea and Environmental Sciences.

UCA Universidad de Cádiz

MEP&M Development of Regional Joint Master Program in Maritime Environmental Protection and Management