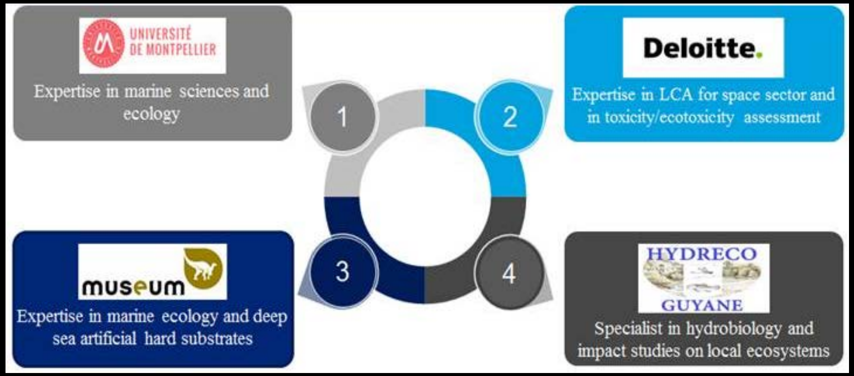
Functional Ecology to Reduce Launchers Impact on Deep Sea (ESA AO 1-8623/16/NL/KML)



Since 2012, the space sector initiated the Clean Space initiative to investigate Life Cycle of Europe's launch vehicles but also space missions. However, up to now ecotoxicological impacts on marine ecosystems of launching, and particularly, of launching residues were under investigated and oversimplified.

The strategic objectives of LAUNCHDESC are:

- To help ESA face the increasing concern of its customers, stakeholders and the general Public about the environmental impacts of space activities, with special focus on the ecotoxicity and human toxicity impacts of launcher stages falling in the ocean (Ariane 5 and Vega).
- To give ESA the possibility to progressively move toward eco-design – by identifying key risk materials and suggesting design/process changes that could possibly reduce the environmental impacts of European launchers.

The approach is three-fold:

1. Characterisation of relevant Launcher materials
2. Marine ecosystems characterisation and preliminary environmental impacts
3. Further study to deepen understanding of environmental impact of disposed launchers

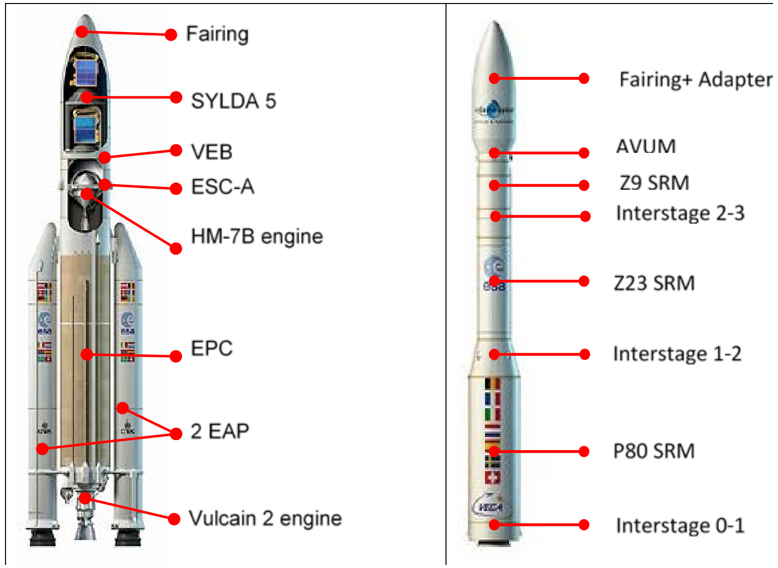
Main objectives:

- Inventory of launching components and materials (metals, plastics, composite, and propellant fuels and residues) and their physical-chemical characteristics
- Marine ecosystems characterisation
- Behaviour and degradation of launcher materials in marine ecosystems
- List of potential ecotoxicological impacts on deep marine ecosystems of launcher components
- Preliminary environmental impacts
- Improvement of Life Cycle Impact Assessment (LCIA) models on marine ecotoxicity and human toxicity

Inventory of launcher components

- Data sources:
  - Ariane 5 and Vega LCA reports
  - Documentation from ESA
  - Literature review (internet search on chemistry websites, Material data sheets, Chemistry Handbook, etc.)
  - Assumptions, either on the mass and/or size of certain components, or on the type/composition of material used
- The inventory was built in several steps:
  - Breakdown of launchers in stages / elements of each stage / components of each element
  - Determination of mass and surface for each component
  - Determination of the composition of components
  - Decomposition in chemical elements for complex materials
  - Compilation of physical-chemical characteristics of each chemical element and raw material from different data sources
- Only aggregated data per stage of the launcher are presented here, without the full composition breakdown for each element

Ariane 5 ECA and Vega launch vehicle



Inventory of launcher components

Gold	<1	<1
Graphite	10-70	<1
GSM 55: Rubber EPDM + silica	2000-8000	<1
Hastelloy X	70-150	<1
Haynes 230 (Nickel alloy)	150-500	<1
Helium	<1	<1
Hydrazine	<1	<1
Hydrogen	500-1000	<1
roxyl-terminated polybutadiene H	500-1000	70-150
Imide	10-70	<1
Incolloy A286	1-10	<1
Inconel 600	150-500	<1
Inconel 625	70-150	<1
Inconel 718	500-1000	<1
Iron	>19 000	500-1000
Iron powder	<1	<1
Iron, ion	10-70	<1
Isocyanates	<1	<1
Lanthanum	<1	<1
Lead	10-70	10-70
Lime	<1	<1
Liquid hydrogen LH2	150-500	<1
Liquid oxygen LOx	1000-2000	<1
Lithium Cobalt Oxide	<1	10-70
Lithium Salts	<1	1-10
Magnesium	150-500	1-10
Magnesium alloy	70-150	<1
Manganese	150-500	10-70
Manganese Dioxide	<1	<1
Mastic Silicone	10-70	<1
Melamine	70-150	<1
Melamine resin foam	70-150	<1
Mercury	<1	<1
MMH Methylhydrazine	<1	<1
Molybdenum	150-500	1-10
NEXTEL	10-70	<1
Nickel	1000-2000	70-150
Nickel alloy 242	150-500	<1
Nickel, ion	1-10	<1
Niobium	10-70	<1
Nitrogen	70-150	1-10
Nitrogen tetroxide N_2O_4	<1	<1
Norcoat	150-500	10-70

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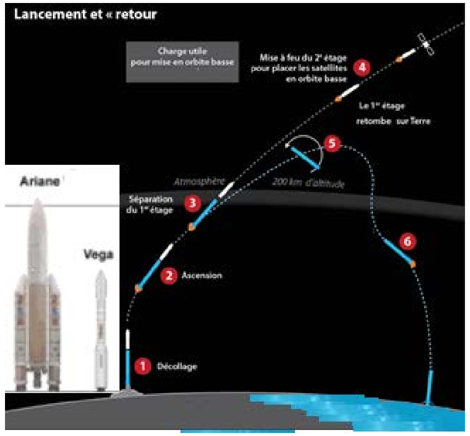
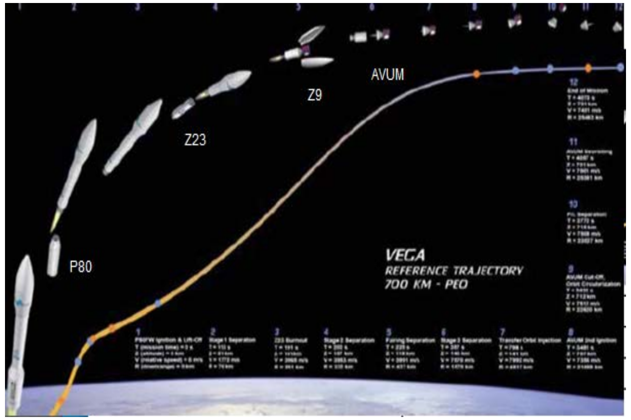
<1
1-10
10-70
70-150
150-500
500-1000
1000-2000
2000-8000
>19 000

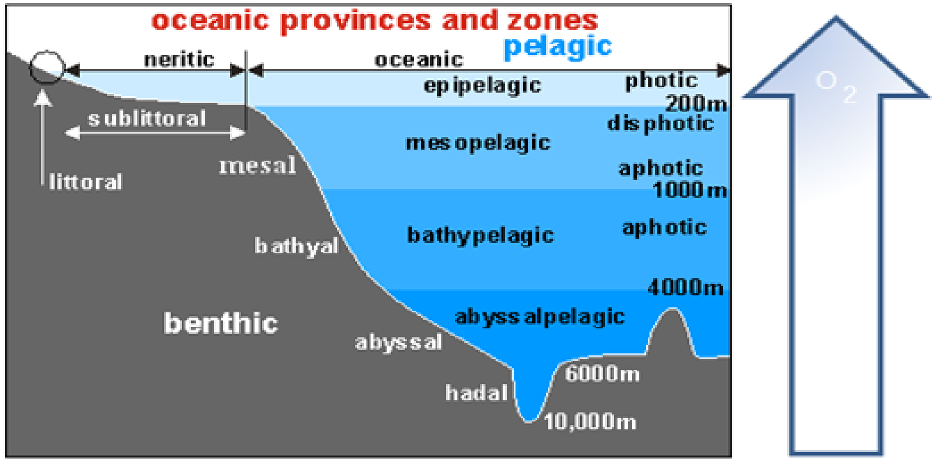
Color code for mass classification of launchers materials (in kg)

Identification and characterization of relevant ecosystems

- Characterization of natural sea ecosystems: typical environmental and biological characteristics of deep sea ecosystem in the zones where launcher residues are known to fall back:
  - The **coastal sea environment** of the ARIANE and VEGA launching ramp in Kourou, French Guyana, that receives most of fuel and lower launching stage residues (especially in the case of VEGA launches, P80) and
  - The **deep sea ecosystem** (abyssal plains) in which are falling most parts of upper launcher stages
- Specific environment conditions : pH, O_2, light, temperature, salinity, organic carbon, microbiota, macrofauna, etc. that will influence the behaviour and degradation of launchers substances in the ocean







Definition of the "neritic" and "oceanic" provinces that are impacted by lower stage and upper stage of ARIANE AND VEGA launchers, respectively

- The degradation products of two families of components were determined :
  - Metals degradation products. They come from the metallic substances or constitutive elements of alloys, They are ions, hydrated ions or oxidized ions
  - Non-metals degradation products (also called organic degradation products). This category gathers mostly resins and polymers, Depending on the aerobic or anaerobic conditions, different chemical substances are released as metabolic products

(Eco)Toxicity of launcher components

- 30 substances out of 178 from the launchers with no quantitative toxicological information available
- 48 substances out of 178 from the launchers with no quantitative ecotoxicological information available
- 26 substances out of 178 identified for which neither toxicological nor ecological quantitative information available
- It must be noted that there is no link between the absence of information on the toxicity and the absence of toxicity or not

Components	Mass in A5-ECA	Mass in VEGA
Bismaleimide Triazine		
Carbon		
Chemosil		
Epoxy resin - curative - 4,4'-DDS diaminodiphenylsulfone		
Glass		
Glass fibre		
Gold		
Helium		
Hydrogen		
Hydroxyl-terminated polybutadiene HTPB		
Lanthanum		
Lithium Cobalt Oxide		
Magnesium alloy		
Mastic Silicone		
Melamine resin foam		
Niobium		
Phenolic resin		
Polyethylene terephthalate PET		
Polyimide PI		
Polyisoprene IR		
Polyphenylene sulfide PPS		
Polypyrrole PPy		
Polyurethane PU		
Silica fibre		
Tetrakis(2-butoxyethyle)orthosilicate		
Viscose		

Substances with no toxicological and ecological information

(Eco)Toxicity of launcher components

- There are 17 substances (out of 178) for which the review has concluded that they are not toxic. This means that those products are not considered to be hazardous for their environment.
- The remaining substances have information about their toxicity or their ecotoxicity.

Components	Mass in A5-ECA	Mass in VEGA
Aramid fibre		
CaCO3		
Carbon		
Carbon Epoxy Fibre		
Cork		
Dow Corning® 1200 RTV Prime Coat- Primer		
Ethylene		
Glue CAF 730		
Gold		
Helium		
Hydrogen		
Lanthanum		
Polyethylene terephthalate PET		
Polyisoprene IR		
Polypropylene PP		
Tantalum		
Viscose		

Non toxic substances

Component	A5	VEGA	Aquatics species
Cadmium	5,5	5,5	0,001
Paint	325	40	0,00
Chlorine	325	0,5	0,014
Copper	1500	325	0,15
Mercury	0,5	0,5	0,35
Sulfur	40	0,5	0,45
Zinc	750	40	0,45
Xylene	325	5,5	3,3
Ethylbenzene	40	5,5	5,1
Toluene	5,5	0,5	7,63
Explosive	40	5,5	7,96
Vinyl acetate	5,5	0,5	14
Dicyclopentadiene	325	0,5	16
Phosphorus	40	5,5	33,2
Phenol	0,5	750	68,8
Potassium hydroxide	5,5	0,5	80
Lead	40	40	126
Lithium Salts	0,5	5,5	158
Graphite	40	0,5	200
Nickel	1500	110	200
Zirconium oxide	40	0,5	200
Alumina	5000	1500	437
Molybdenum	325	5,5	800
Lime	0,5	0,5	1 070
Titanium tetrabutanolate	0,5	0,5	1 925
Antimony trioxide Sb2O3	110	0,5	2 000
EPDM rubber	40	1500	2 000
Petroleum naphtha	5,5	0,5	2 200
Bentonite	110	0,5	19 000
Ceramic	0,5	0,5	20 000
Chromium(III) oxide	0,5	0,5	20 000
CaCO3 (calcium carbonate)	0,5	0,5	56 000

Substances with EC50 for aquatic species

Preliminary risk assessment

- Risk = f [(eco)toxicity, quantity of substance] *where f is a function chosen and adapted for each case, often multiplication*
- The concentration of substances in the marine environment cannot be assessed here as no models are available to calculate
  i. the amount of substance effectively released in the water by the launcher and the components, and even less for degradation products,
  ii. the diffusion rate of substances in the water, which is a non-static open system.
- However, with the hypothesis of all substances released will behave the same (in terms of diffusion) in the ocean, the initial quantity of substance available is the main parameter to compare the exposure.
- The adopted methodology was to multiply the amount of substance and the inverse of the EC50 (1/EC50).
- For the two launchers, the top 5 of the most risk substances is the same: paint, chlorine, cadmium, copper, zinc
- Xylene, alumina, mercury, ethylbenzene, nickel, Sulphur and explosives are also part of the substances that can pose the highest risks to the marine environment

Ranking – from the highest risk (in red) to the lowest (no color) – of the substances for which EC50s of fishes were available in each launcher

Component, for A5		Component, for VEGA
Paint		Paint
Chlorine		Cadmium
Copper		Copper
Cadmium		Zinc
Zinc	Top 5	Chlorine
Xylene		Phenol
Sulfur		Alumina
Dicyclopentadiene		Xylene
Alumina		Mercury
Ethylbenzene	Top 10	Sulfur
Nickel		Ethylbenzene
Explosive		EPDM rubber
Mercury		Explosive
Phosphorus		Nickel
Toluene	Top 15	Lead
Molybdenum		Phosphorus
Vinyl acetate		Toluene
Lead		Vinyl acetate
Graphite		Lithium salts
Zirconium oxide		Dicyclopentadiene
Potassium hydroxide		Molybdenum
Antimony trioxide Sb2O3		Potassium hydroxide
EPDM rubber		Graphite
Phenol		Zirconium oxide
Bentonite		Lime
Lithium salts		Titanium tetrabutanolate
Petroleum naphtha		Antimony trioxide Sb2O3
Lime		Petroleum naphtha
Titanium tetrabutanolate		Bentonite
Ceramic		Ceramic
Chromium(III) oxide		Chromium(III) oxide
Caco3 (calcium carbonate)		Caco3 (calcium carbonate)

Estimation of behaviour and toxicity of components of launchers in marine conditions

- Literature review for fate and behaviour of Ariane and Vega components and materials
- Metallic corrosion in seawater and toxicity were followed in a range of conditions for a set of representative alloys used in aerospace vessels
- Similar experiments were performed for a set of representative organic components of Vega and & Ariane 5 launchers
- Follow-ups were performed in representative ecosystems (French Guiana)

Selected materials

metals	non-metals
Stainless steel	Epoxy resin
Aluminium 2024	Phenolic resin
Titanium 6Al 4V	Polyurethane

Metallic compounds

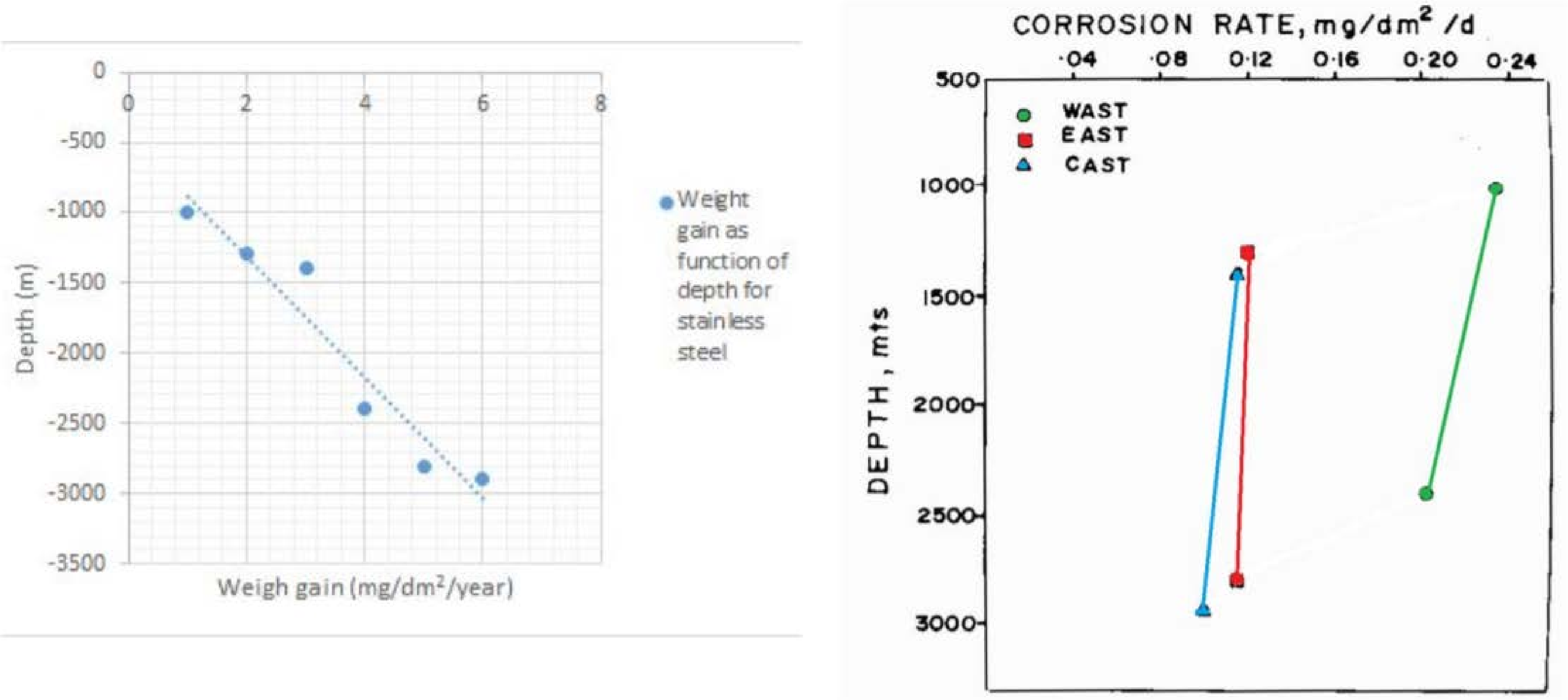
Literature review

On-site studies in French Guyana

Model experiments in laboratory conditions

Metallic corrosion as a function of depth

Very limited relevant bibliography is available on the "**Biodegradation**" or "**biofilm allowing corrosion**" for alloys used in launcher composition and aerospace manufacture



weight gain and corrosion rates as a function of depth for various metalic alloys (adapted from Sawant and Wagh, 1990)

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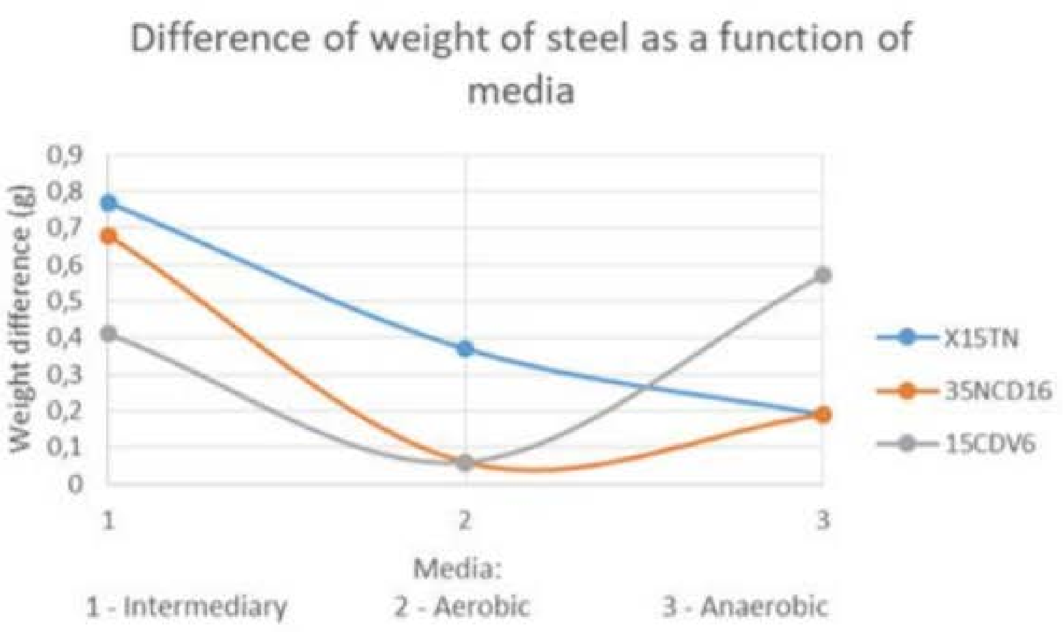
Metallic corrosion as a function of composition and marine oxygen level

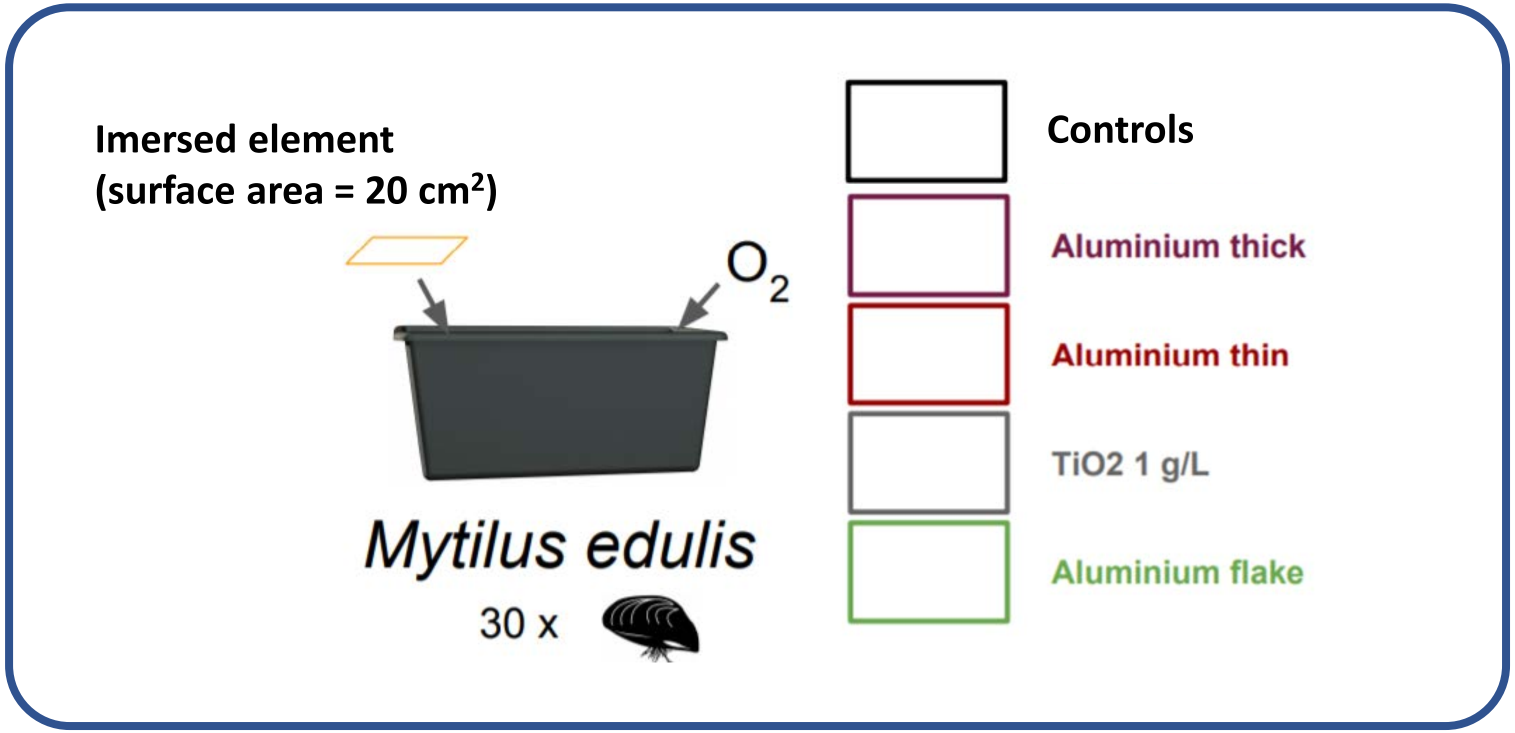
- Corrosion in seawater estimated from weight in aerobic, anaerobic and mixed conditions (our work, unpublished results)

Steel		Weight before	Weight after	difference
X15TN	Tank 1	120,36	119,59	0,77
	Tank 2	120,05	119,68	0,37
	Tank 3	120,08	119,89	0,19
35NCD16	Tank 1	122,88	122,2	0,68
	Tank 2	123,66	123,6	0,06
	Tank 3	122,89	122,7	0,19
15CDV6	Tank 1	122,7	122,29	0,41
	Tank 2	122,44	122,38	0,06
	Tank 3	122,56	121,99	0,57



Ecotoxicity evaluation

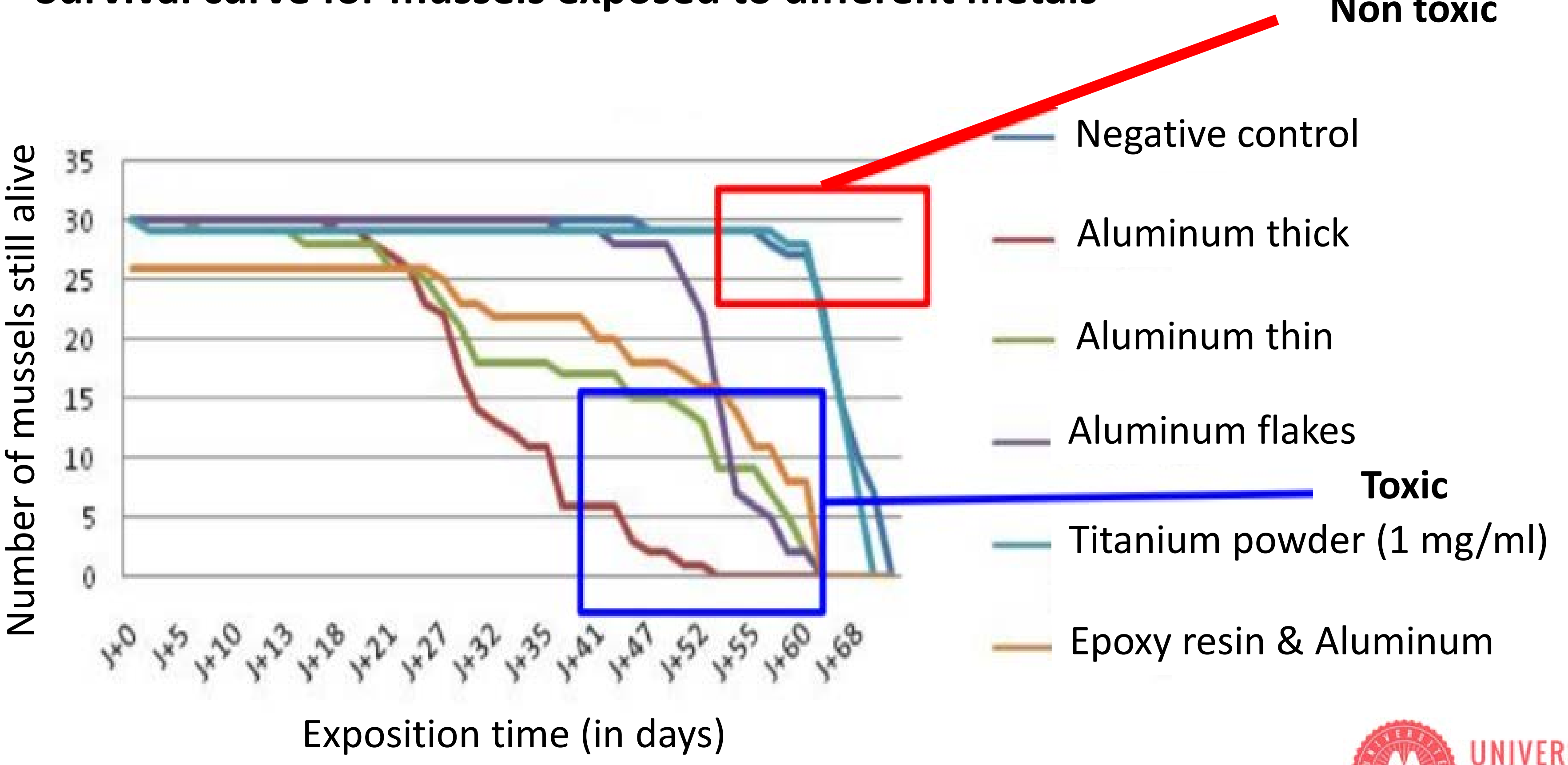
Macrofauna *in vitro*



Ecotoxicity evaluation

Macrofauna *in vitro*

Survival curve for mussels exposed to different metals



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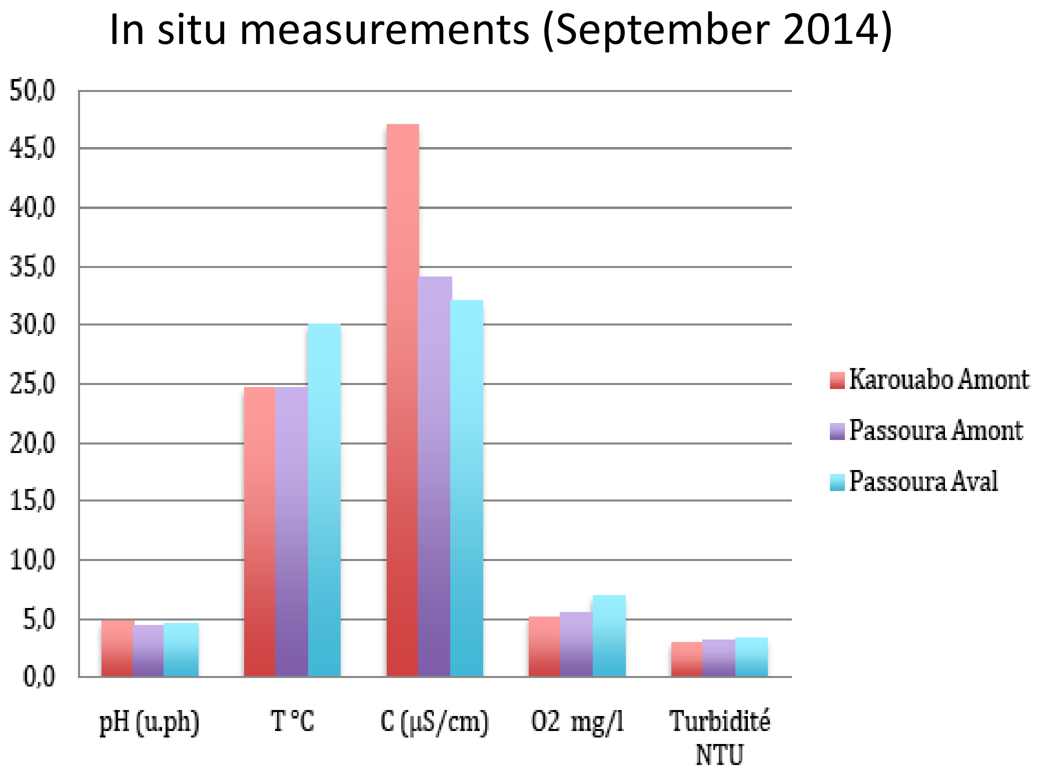
IN SITU IMPACT STUDIES in French Guyana

Water Quality

- Turbidity, Ph & Conductivity values are low
- Clear waters
- Physico-chemical characteristics of the environment change according to the season

Fish populations

- Sites in good environmental health
- Strong imbalance in local fish population distribution (Vigouroux & Guillemet, 2006)



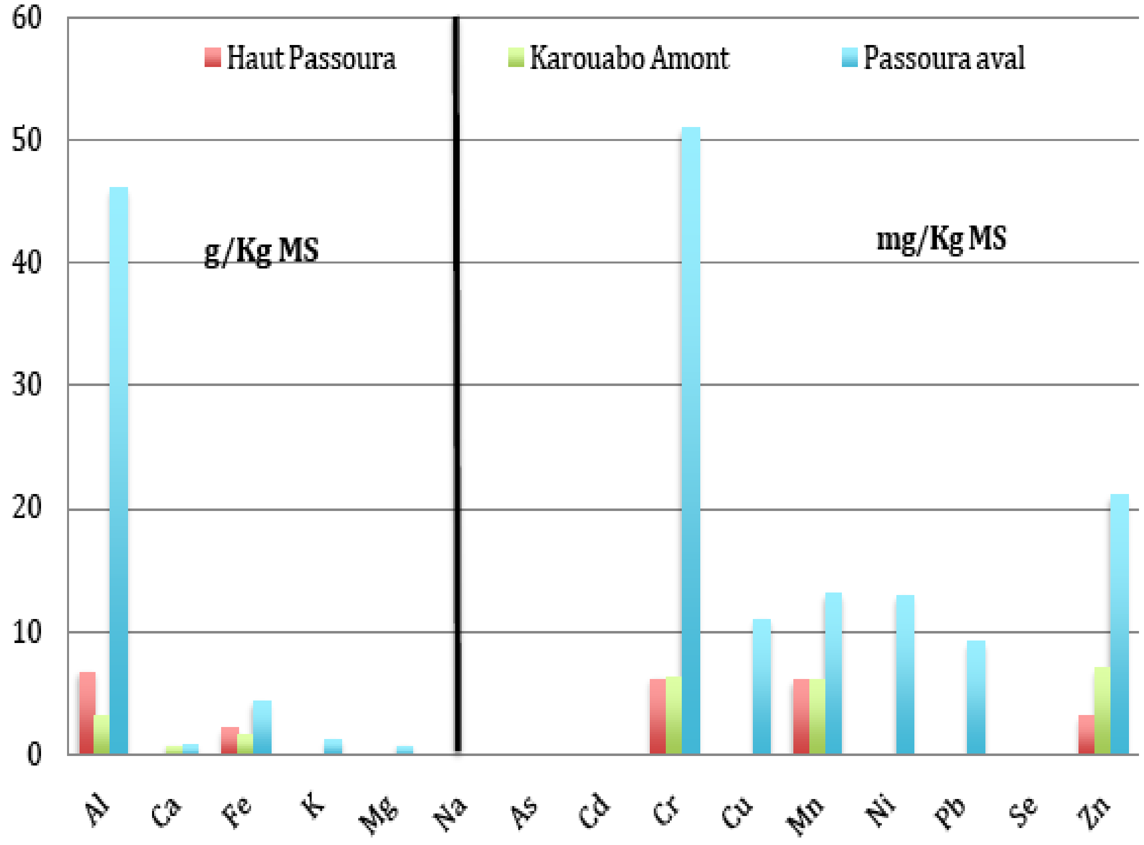
Therefore, the successive launches of Ariane can induce the release of various products into the environment (including aluminum), with potentially a non-negligible impact on fish

HYDRECO GUYANE

Sediment status

In some locations, aluminum concentrations are high

September 2014



Anthropogenic contaminations ?

Organic compounds

Literature mining

Behavior in seawater

Ecotoxicological assessment in laboratory conditions

no toxicological data

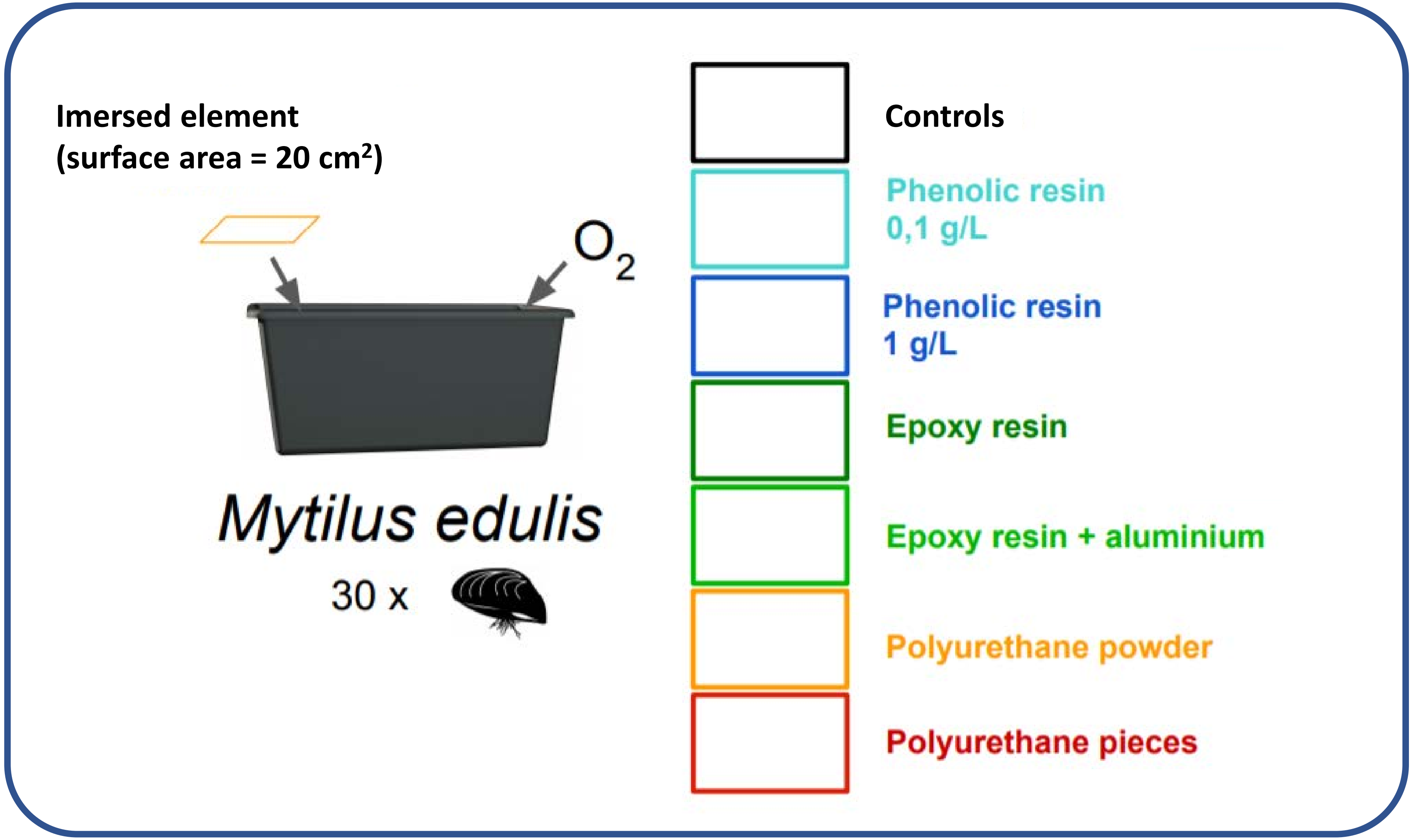
Component
Aluminium
Bismaldeide triazine
Carbon
Chemosil
Chromium
Epoxy resin - curative - 4,4'-DDS diaminodiphenylsulfone
Glass
Glass fibre
Gold
Helium
Hydrogen
Hydroxyl-terminated polybutadiene HTPB
Lanthanum
Lithium Cobalt Oxide
Magnesium
Magnesium alloy
Mastic Silicone
Melamine resin foam
Niobium
Phenolic resin
Polyethylene terephthalate PET
Polyimide PI
Polyisoprene IR
Polyphenylene sulfide PPS
Polypyrrole PPy
Polyurethane PU
Polyvinyl chloride PVC
Silica fibre
Tetrakis(2-butoxyethyle)orthosilicate
Viscose
Zinc
Zirconium oxide

no ecological data

Components	
Antimony	Nylon
BeO (beryllium oxide)	Paper
Bismaldeide triazine	Phenol formaldehyde resin
Carbon	phenolic resin
Chemosil	Polycarbonate PC
Cobalt	Polyethylene terephthalate PET
Epoxy resin - curative - 4,4'-DDS diaminodiphenylsulfone	Polyimide PI
Epoxy resin (MY720)	Polyisoprene IR
Glass	Polyphenylene sulfide PPS
Glass fibre	Polypyrrole PPy
Glue Wacker T77	Polytetrafluoroethylene PTFE (Teflon)
Gold	Polyurethane PU
Helium	Silica
Hydrogen	Silica fibre
Hydroxyl-terminatedpolybutadiene HTPB	Silicon
Lanthanum	Silicon rubber
Lithium Cobalt Oxide	Silver
Magnesium alloy	Tetrakis(2-butoxyethyle) orthosilicate
Manganese Dioxide	Titanium
Mastic Silicone	Titanium dioxide
Melamine	Tungsten
NEXTEL	Vanadium
Melamine resin foam	Viscose
Niobium	Zirconium
Nitrogen tetroxide N2O4	

Ecotoxicity evaluation

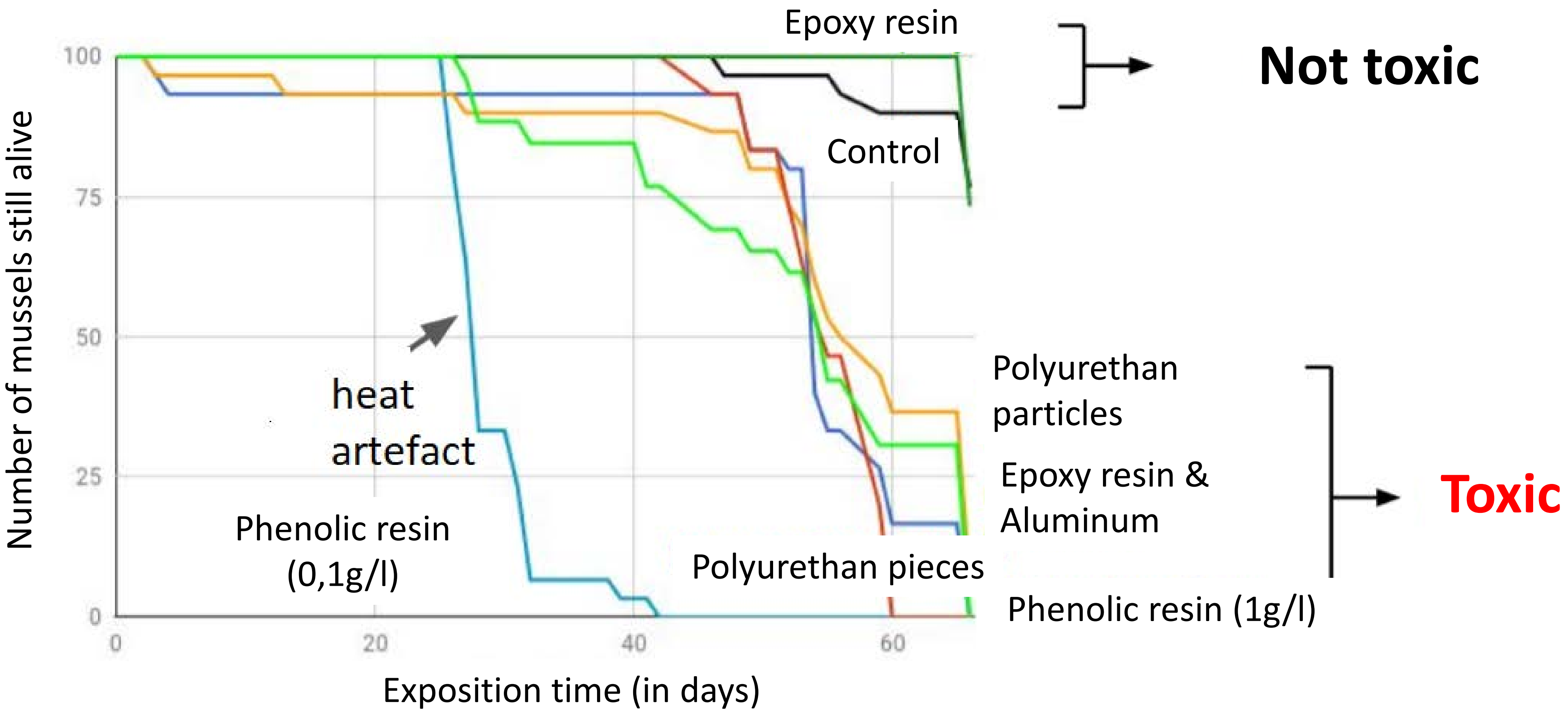
Macrofauna *in vitro*



Ecotoxicity evaluation

Macrofauna *in vitro*

Survival curves for mussels exposed to components

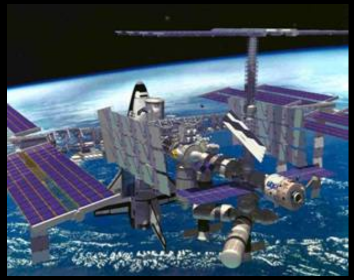


conclusions

- Behaviour and toxicity varies depending on substrate but also on environmental conditions (e.g. depth, oxygen availability)

- Time has also to be taken into consideration, no rapid conclusion can be driven from available literature and experimental approach during the project

- Longer impact has to be investigated



Thank you for your attention!

Any questions?