MELISSA
MICRO-ECOLOGICAL LIFE SUPPORT SYSTEM ALTERNATIVE

CREATING A CIRCULAR FUTURE

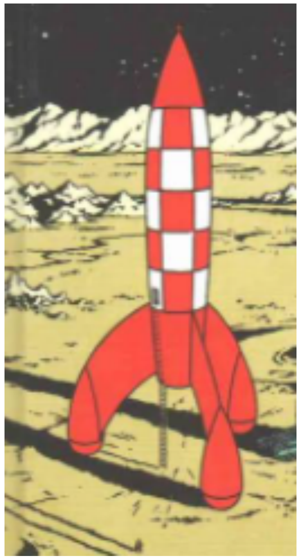
Assessing impacts of over fifty years of launching activities on marine ecosystems

(the metal compounds case)

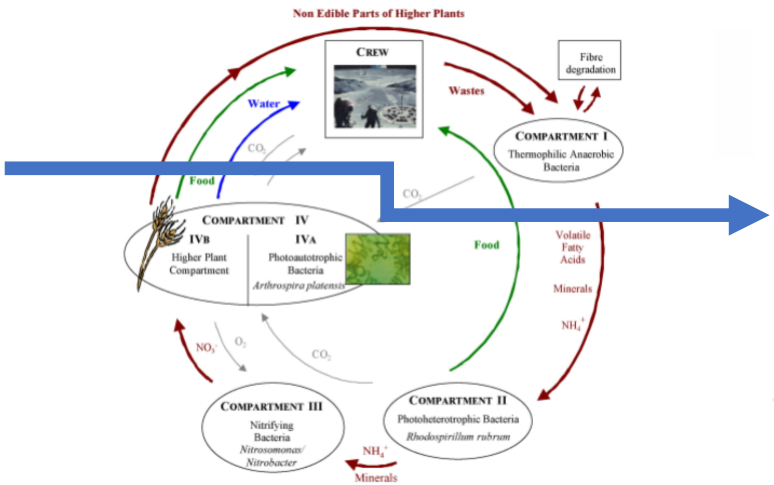
Tatiana Vallaeys
Université de Montpellier

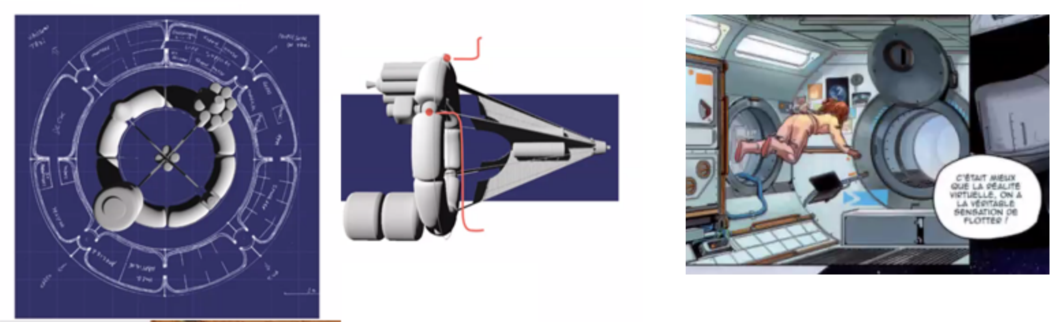
esa
HYDRECO GUYANE
museum
Deloitte.
fds FACULTÉ DES SCIENCES MONTPELLIER
UNIVERSITÉ DE MONTPELLIER

The way toward a « circular future »?

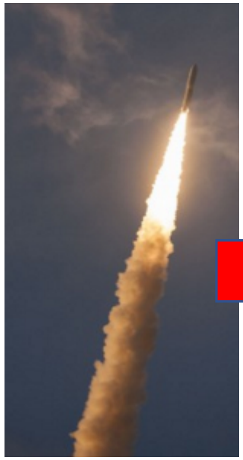


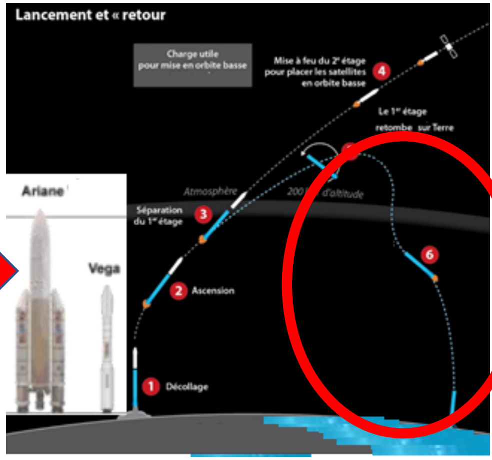
Source : **Hérgé** Editions Castelman 1953





Source : didier schmitt, this conference
copyright: D. Schmitt, Red Safari, Editions Weyrich





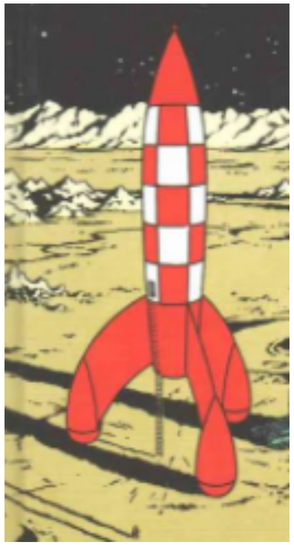
Since 2008 the Marine Strategy Framework Directive (2008/56/EC) of the European Parliament imposes to preserve and protect the marine environment

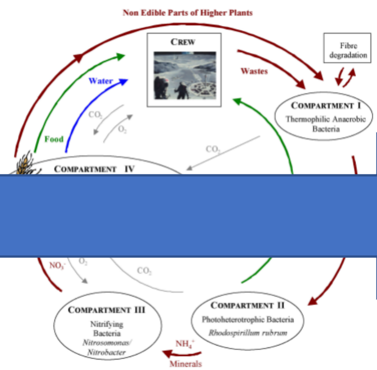
Since 2012, the space sector initiated the Clean Space initiative to investigate Life Cycle of Europe’s launch vehicles and missions.

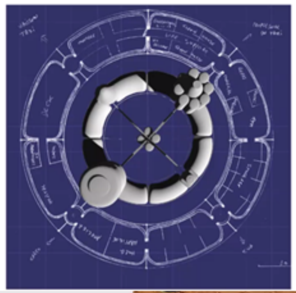
up to now ecotoxicological impacts on marine ecosystems of launching, and particularly, of launching residuals were under investigated and oversimplified.

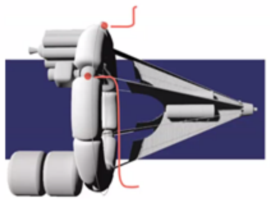
Our objectives were:

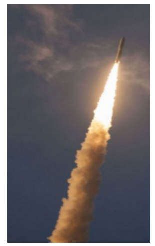
- To help ESA to face the increasing concern of its customers, stakeholders and the general Public about environmental impact of launching
- To give ESA the possibility to progressively move toward ecodesign – by identifying key risk materials and suggesting design/process changes that could possibly reduce environmental impact of ESA launchers.

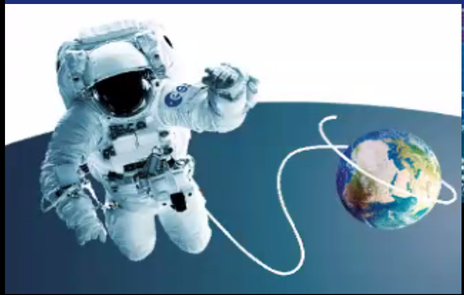






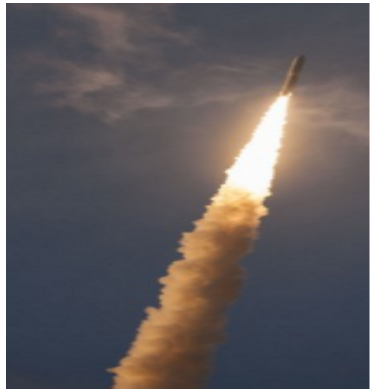






Functional Ecology to Reduce Launchers Impact on Deep Sea (ESA AO 1-8623/16/NL/KML)

ESTIMATED RELEASE to the SEA



INDUSTRY
300-500 billion kg/year
(heavy metals, sludges, solvents..)
ESTIMATED RELEASE
to the SEA
12700 kg/sec

SUN SCREEN
25000 t/year
ESTIMATED RELEASE
to the SEA
0,8 l/sec

SHIPPING
1million t /year
(gaz discharge)
ESTIMATED RELEASE
to the SEA
0,76 kg/sec

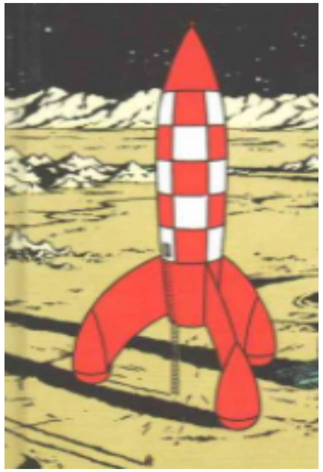
LAUNCHING

?

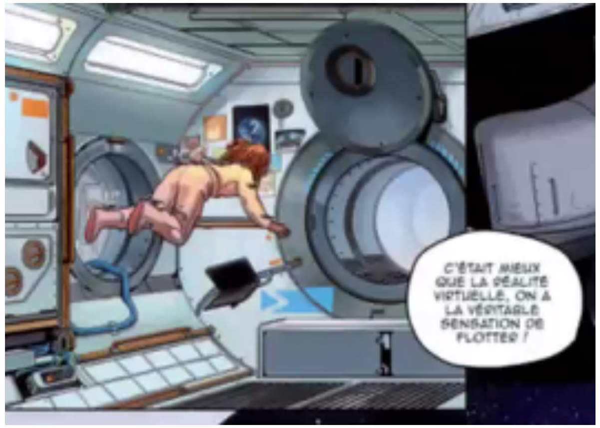
MELiSSA
MICRO-ECOLOGICAL LIFE SUPPORT SYSTEM ALTERNATIVE

Source: Comparative analysis with main reported contaminations (from UNESCO data)

Global IMPACT assessements



Source : Hérgé
Editions Castelman
1953



Source D. Schmitt, Red Safari
Editions Weyrich
2020

From early stage

to 21st century?

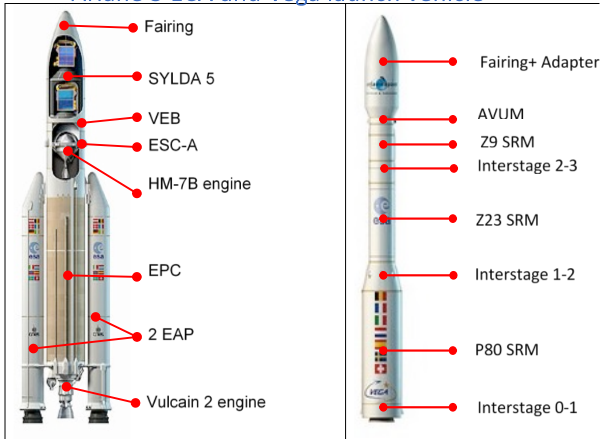
MELiSSA
MICRO-ECOLOGICAL LIFE SUPPORT SYSTEM ALTERNATIVE

Inventory of launcher components

- Data sources:
  - Ariane V 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:
  - Determination of mass and surface for each component..
  - Decomposition in chemical elements for complex materials.
  - Compilation of physical-chemical characteristics of each chemical element and raw material from different data sources

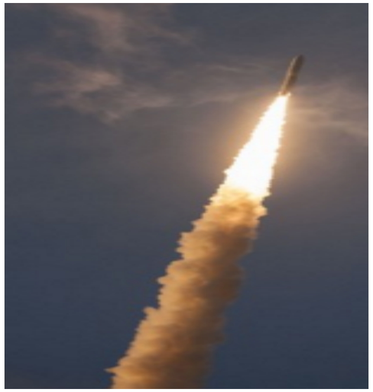
Ariane 5 ECA and Vega launch vehicle



Estimation of total mass of launching materials returning to earth

Materials and chemical elements	Mass per launchers (kg/launch)		
	A5 - ECA	A5 - ES	Sum of VEGA
Alumine	0,31	0,27	0,23
Aluminium	20852,18	19249,43	2605,18
Ammonium perchlorate	644,18	644,18	162,04
Antimony	96,70	96,70	0,00
Antimony trioxide Sb2O3	0,08	0,06	0,05
Aramid fibre	125,40	125,40	500,50
B/KNO3 (pyrotechnic mixture)	2,40	0,00	0,00
Bentonite	73,35	73,35	0,00
BeO	0,00	0,00	0,00
Bismaleimide Triazine	0,00	0,01	0,01

ESTIMATED RELEASE to the SEA



INDUSTRY
300-500 billion kg/year
(heavy metals, sludges, solvents..)
ESTIMATED RELEASE
to the SEA
12700 kg/sec

SUN SCREEN
25000 t/year
ESTIMATED RELEASE
to the SEA
0,8 l/sec

SHIPPING
1million t /year
(gaz discharge)
ESTIMATED RELEASE
to the SEA
0,76 kg/sec

LAUNCHING

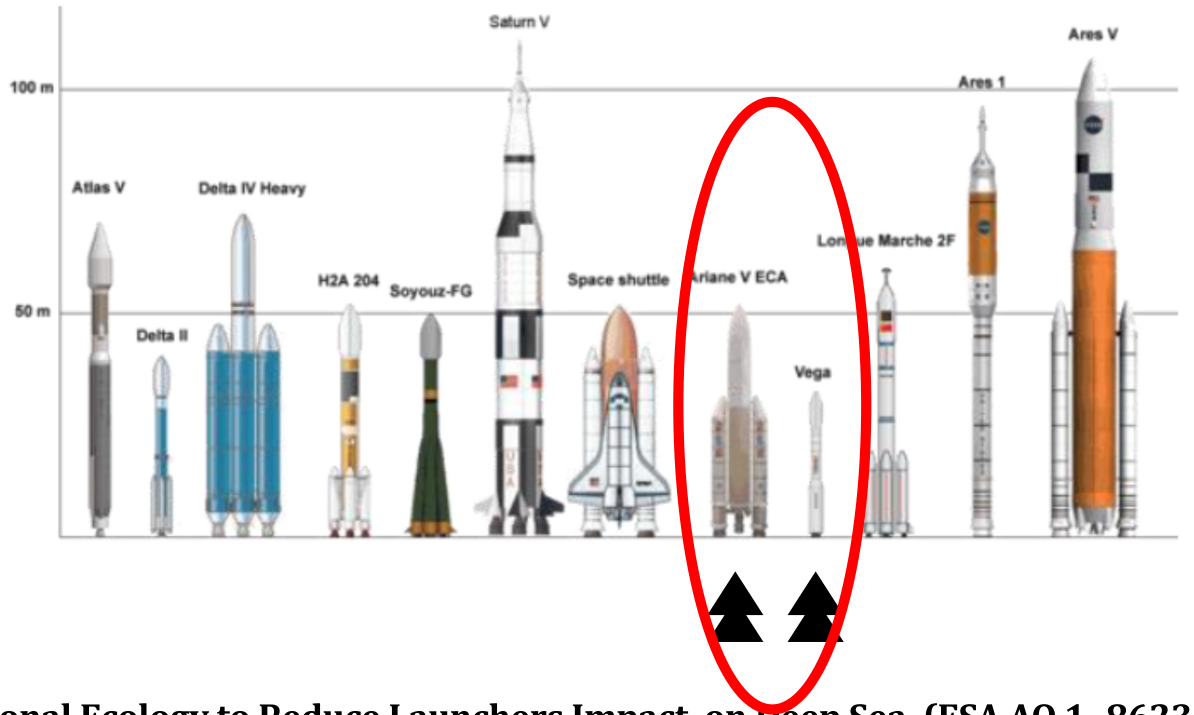
ESTIMATED RELEASE
to the SEA
14280 t/year
0,45 kg/sec

Source: Comparative analysis with main reported contaminations (from UNESCO data)

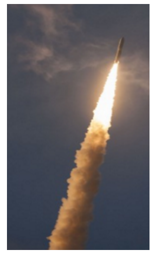
esa · UNIVERSITÉ DE MONTPELLIER · FdS FACULTÉ DES SCIENCES MONTPELLIER · Deloitte. · museum · HYDRECO GUYANE

:

I-Launcher composition (ARIANE and VEGA) : (Eco) toxicity of components



MELISSA
MICRO-ECOLOGICAL LIFE SUPPORT SYSTEM ALTERNATIVE



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

Substances with known toxicological or ecotoxicological hazards

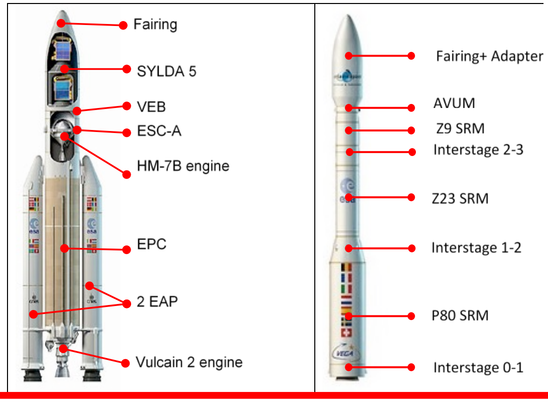
List of LD50, LC50 and EC50 of substances

Component	Mass	Mass	Mammals	Aquatic species		
	A5	VEGA	LD50 (mg/kg)	LC50 (mg/L)		EC50 (mg/L)
Alumina			> 5000 (oral, rat)	> 2.3 (4h, inhalation, rat)	> 218.64 (96h, fish)	
Aluminium			2000 mg/kg (oral, rat)			1,5 (algae)
Ammonium perchlorate			1900 (oral, rat)			2 (bacteria)
Antimony trioxide Sb2O3			34600 (oral, rat)		> 1,000 (96h, fish)	>1,000 (daphnia magna) 67 (algae)
Antimony			7 (oral, rat)		261 (24h, larvae) 4.92 (24h, flea) 206 (72h, algae)	
Aramid fibre			7500 (oral, rat)			
Bentonite			35 (intravenous, rat)		19000 (96h, fish)	
BeO (beryllium oxide)			2062 (oral, mouse)			
Boron			650 (oral, rat)			
Bromine			2.600 (oral, rat)	2,700 (inhalation, rat)		Fish > 10 (fish) 10 (daphnia magna)
CaCO3 (calcium carbonate)			6450 (oral, rat)		56 000 (48h, fish)	
Cadmium			2330 (oral, rat)		0,001 (96h, fish)	0.024 (daphnia magna) 0.023 (algae)
Ceramic			>22,500 (oral, rat)		> 10 000 (72h, fish)	
Chlorine				293 ppm (1h, inhalation,	0.014 (96h, fish)	0.019 (daphnia magna)

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

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

(Eco)Toxicity of launcher components



Our study showed that

- There were 30 substances from the launchers with no quantitative toxicological information available.
- There are 48 substances from the launchers with no quantitative ecotoxicological information available.
- There are 26 substances for which there are neither toxicological nor ecological quantitative information available
- For the two launchers, the top 5 of the most risk substances were : paint, chlorine, cadmium, copper, zinc

Alumina, mercury, ethylbenzene, nickel, sulphur are also part of the substances that can pose the highest risks to the marine environment

Metallic compounds

Literature review

Model experiments in laboratory conditions

On-site studies in French Guyana

Toxicity of components of launchers in marine conditions is function of their composition and behavior

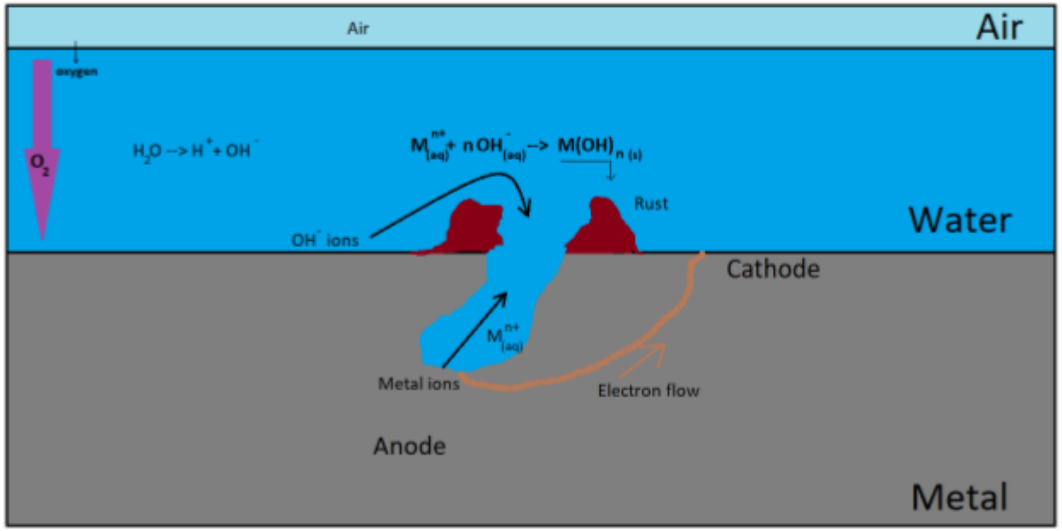
However, previous data were obtained with the hypothesis of same substance release and same behavior (in terms of diffusion) in the ocean, while:

- Diffusion varies according to composition
- Diffusion varies according to environmental conditions

esa UNIVERSITÉ DE MONTPELLIER fds Deloitte. museum HYDRECO GUYANE

REACTIVITY =f(environmental conditions)

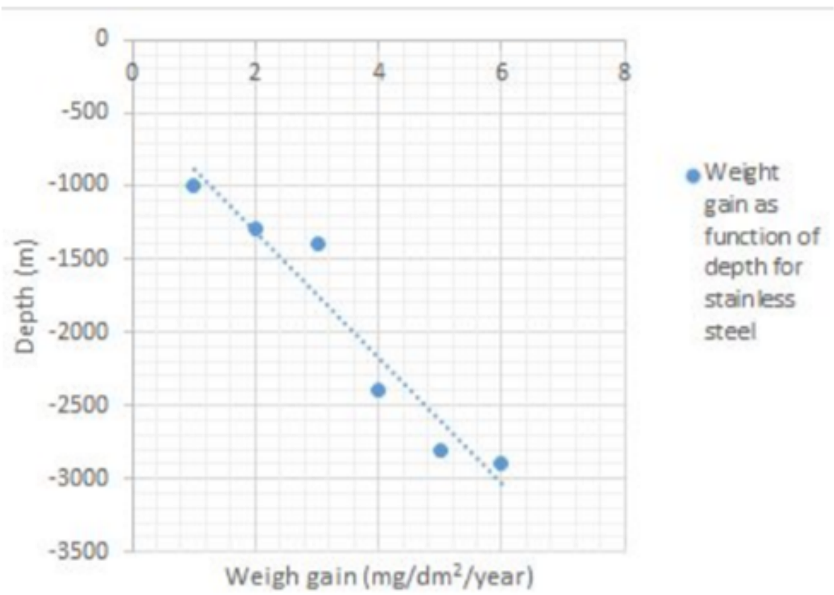
- oxydo-reduction
- Influencing parameters
  - salinity
  - depth
  - pH
  - dissolved O2



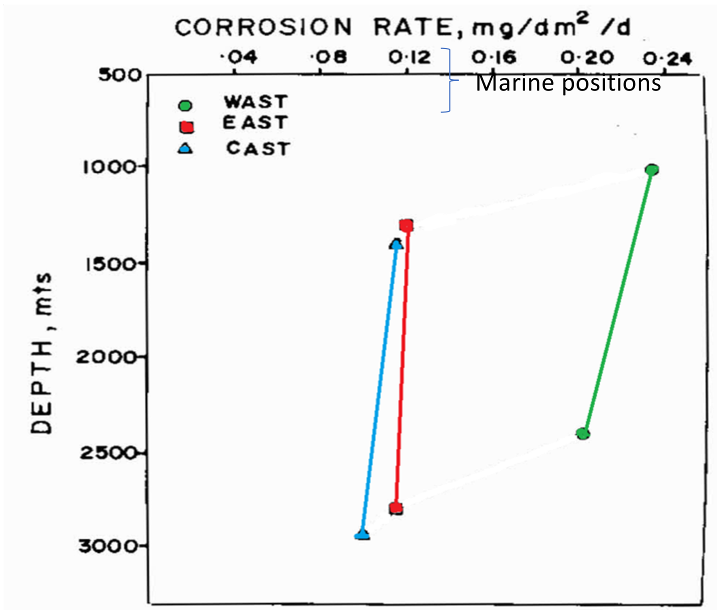
metal oxydation in sea water (KM3NeT Consortium, 2012)

Metal corrosion as a function of depth varries with the metal

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



! Inverse relationship for the corrosion rate of aluminium with depth



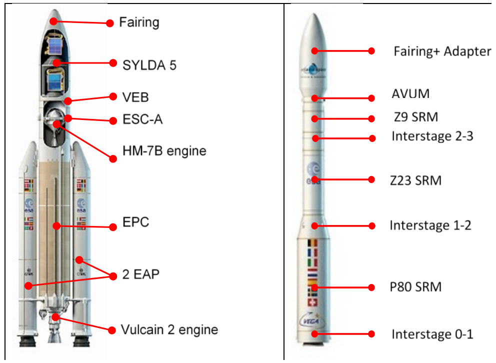
(adapted from Sawant and Wagh, 1990)

ESA
UNIVERSITÉ DE MONTPELLIER
fds
Deloitte.
museum
HYDRECO GUYANE

Metal (bio) corrosion in sea water = f (compounds composition)

metal	corrosion product in sea water	References
Fe	FeS ; Fe_2O_3 ; Fe_3O_4 ; $Fe(OH)_2$; $Fe(OH)_3$	Lee et Al. (2013) Byrne & Kester (1976)
Al	$Al^{3+}_{(aq)}$; $Al(OH)_4^-{}_{(aq)}$; $Al(OH)_{3(aq)}$; $Al(OH)_2^+{}_{(aq)}$; $AlO_2^-{}_{(aq)}$; $Al_2(SO_4)_{3(s)}$; $Al_2O_{3(s)}$; $Al(OH)_2Cl_2^-$	Sherif (2011) Wharton et Al. (2005)
Ti	TiO ; TiO_2 ; TiO_3 ; TiO_xN_y (TiN)	Totolin et Al. (2016)
Cu	Cu_2O ; CuO	Wharton et Al. (2005)
Cr	Cr^{3+} ; $Cr(OH)_2^+$; $Cr(OH)_3$; $Cr(OH)_4^-$; $HCrO_4^-$; CrO_4^{2-} ; Cr_2O_3	Van der Weijden & Reith (1982) Fukai (1967) Nakayama et Al. (1981)
V	VO^{2+} ; H_3VO_4 ; $H_2VO_4^-$; HVO_4^{2-} ; VO_4^{3-} ; VO^{2+}	Nukatsuka et Al. (2002)
Ni	Ni^{2+} ; NiO	Van den Berg et Al. (1987) Gong et Al. (2011)
Zr	ZrO^{2+}	McKelvey & Orians (1993)
Mg	$Mg(OH)_2$; Mg^{2+} ; MgO	Zou et Al (2011) Pardo et Al. (2008)
Co	Co^{2+}	Ellwood & Van den Berg (2001)

Experimental set-up



- metallic corrosion in seawater and toxicity were followed in a range of conditions for a set of representative alloys used in aerospace vessels

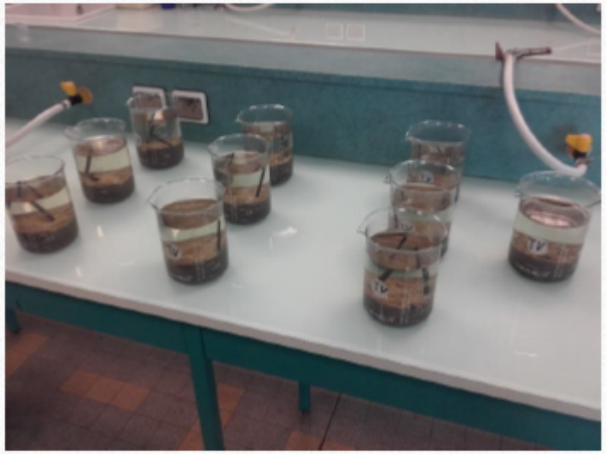
  - Experimental set ups were designed for a set of representative metal components of VEGA and & ARIANE LAUNCHERS

  - Follow-ups were performed in representative ecosystems (French Guyana)

esa · UNIVERSITÉ DE MONTPELLIER · fds FACULTÉ DES SCIENCES MONTPELLIER · Deloitte. · museum · HYDRECO GUYANE

EXPERIMENTAL SET UP

- stainless steel and carbon steel
- sterile and non-sterile sea water
- 3 conditions
  - aerobiosis
  - anaerobiosis
  - interface



ESA · Université de Montpellier · FdS Faculté des Sciences Montpellier · Deloitte. · museum · HYDRECO GUYANE

Selected steels

X15TN (stainless steel)

Witness

35NCD16 (carbon steel)

component of launchers

15CDV6 (carbon steel)

component of launchers

CHEMICAL COMPOSITION

	C	Si	Mn	Cr	Mo	V	N	Ni
min.	0.37	-	-	15.00	1.50	0.20	0.16	-
max.	0.45	0.60	0.60	16.50	1.90	0.40	0.25	0.30

COMPOSITION

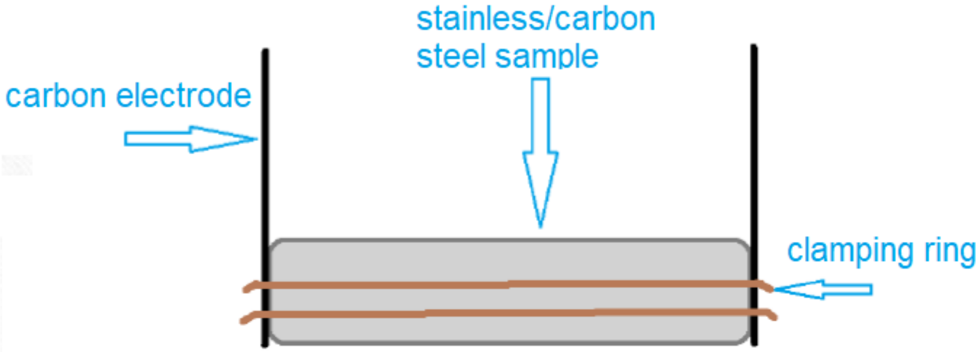
Carbone 0,15
Chrome 1,25
Molybdène 0,90
Vanadium 0,25

COMPOSITION

Carbone 0,35
Nickel 3,80
Chrome 1,70
Molybdène 0,30

Experimental set- up

- pH follow-up
- measures of electric potential
- measures of sample weigth
- electron microscopy observations
- ICP-MS elemental analysis
- ecotoxicological follow up

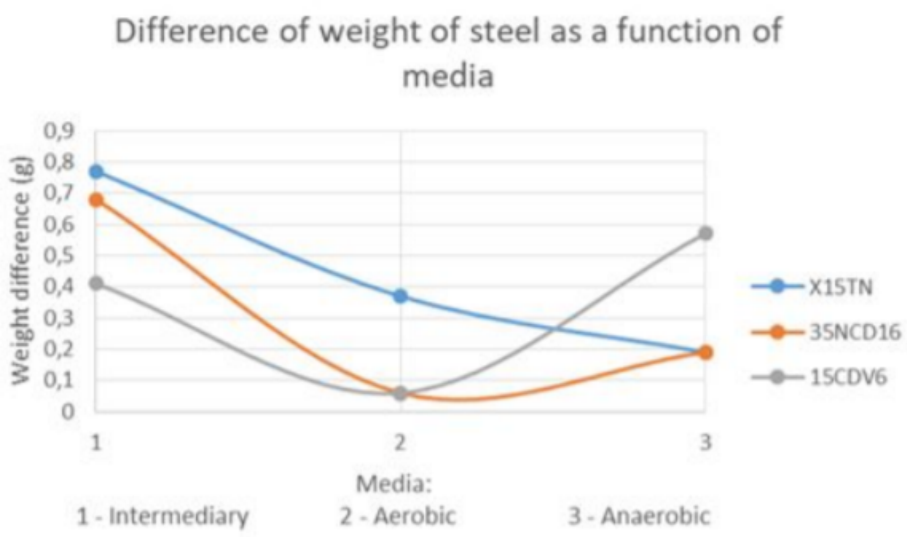


ESA · Université de Montpellier · FdS Faculté des Sciences Montpellier · Deloitte. · museum · HYDRECO GUYANE

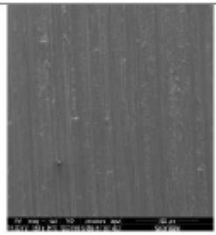
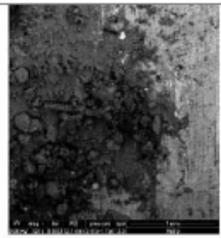
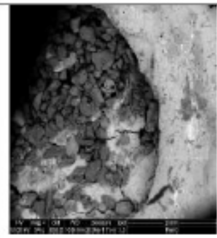
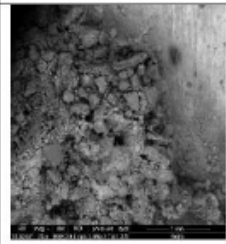
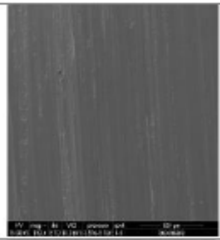
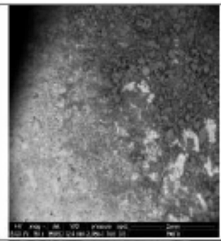
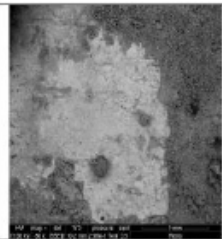
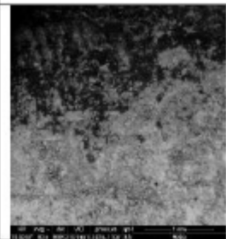
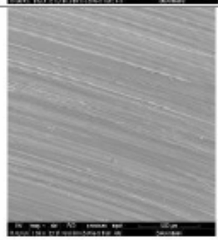
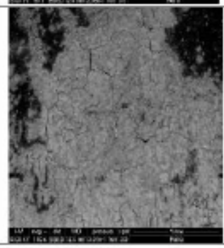
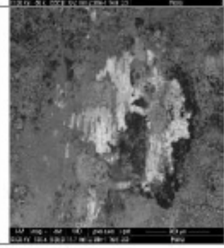
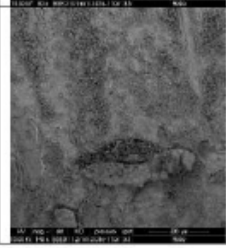
Metal corrosion as a function of composition and marine oxygen level

- 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

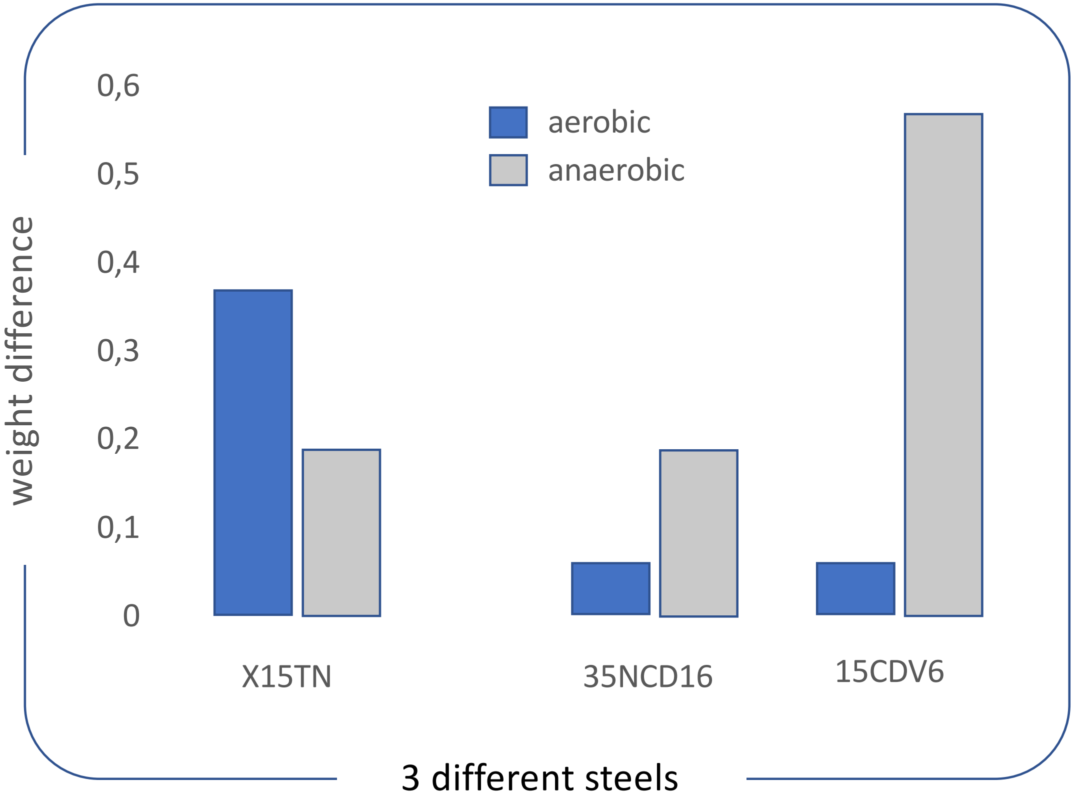


MEB analysis confirmed that (bio) corrosion depends on conditions

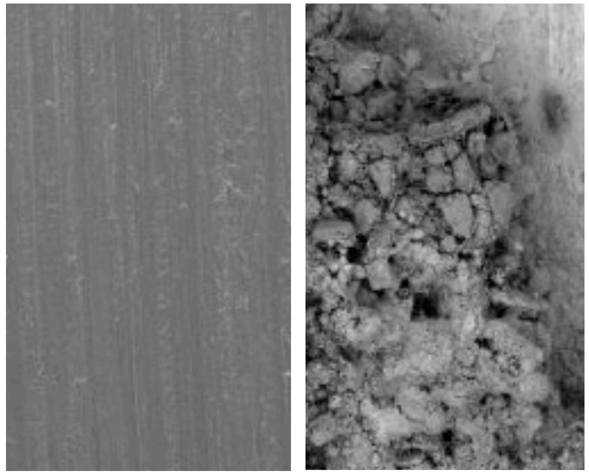
échantillons	Avant	Bac 1 après	Bac 2 après	Bac 3 après
X15TN				
35NCD16				
15CDV6				

Metallic corrosion as a function of metallic composition and seawater oxygen level

Corrosion in seawater estimated from weight in **aerobic** & **anaerobic** conditions

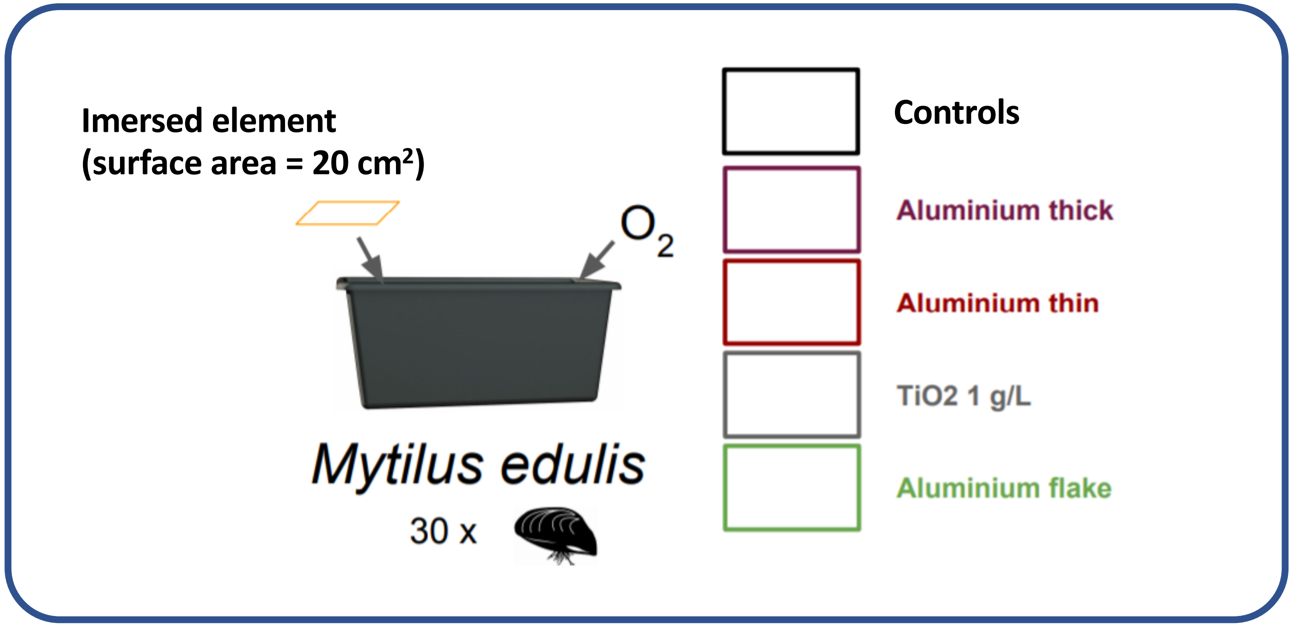


Surface pitting and cracks



Ecotoxicity evaluation

Macrofauna *in vitro*



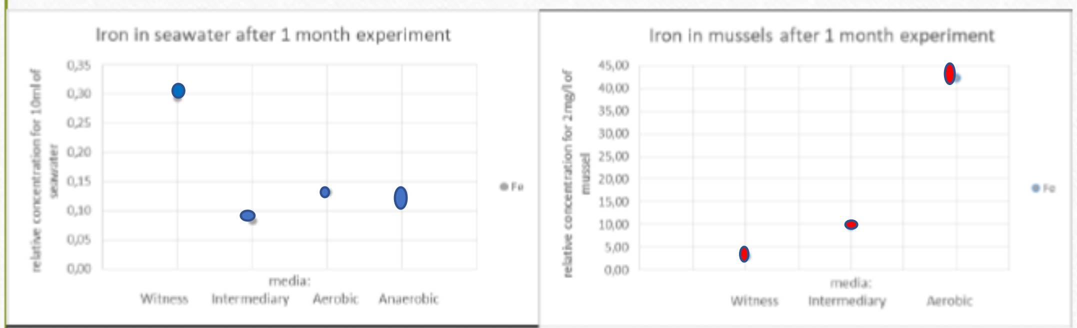
Metal analysis (after 1 month) in sea water and mussels

Iron (in ppb)

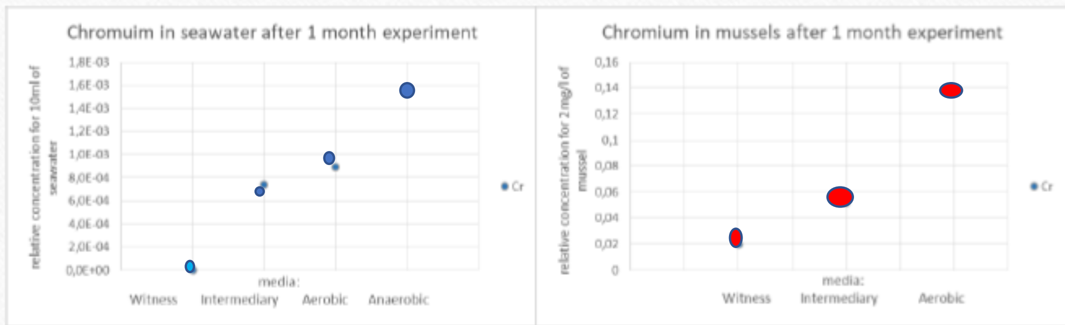
Sea water: stable mussels : increase

Chromium (in ppb)

Sea water: increase mussels : increase



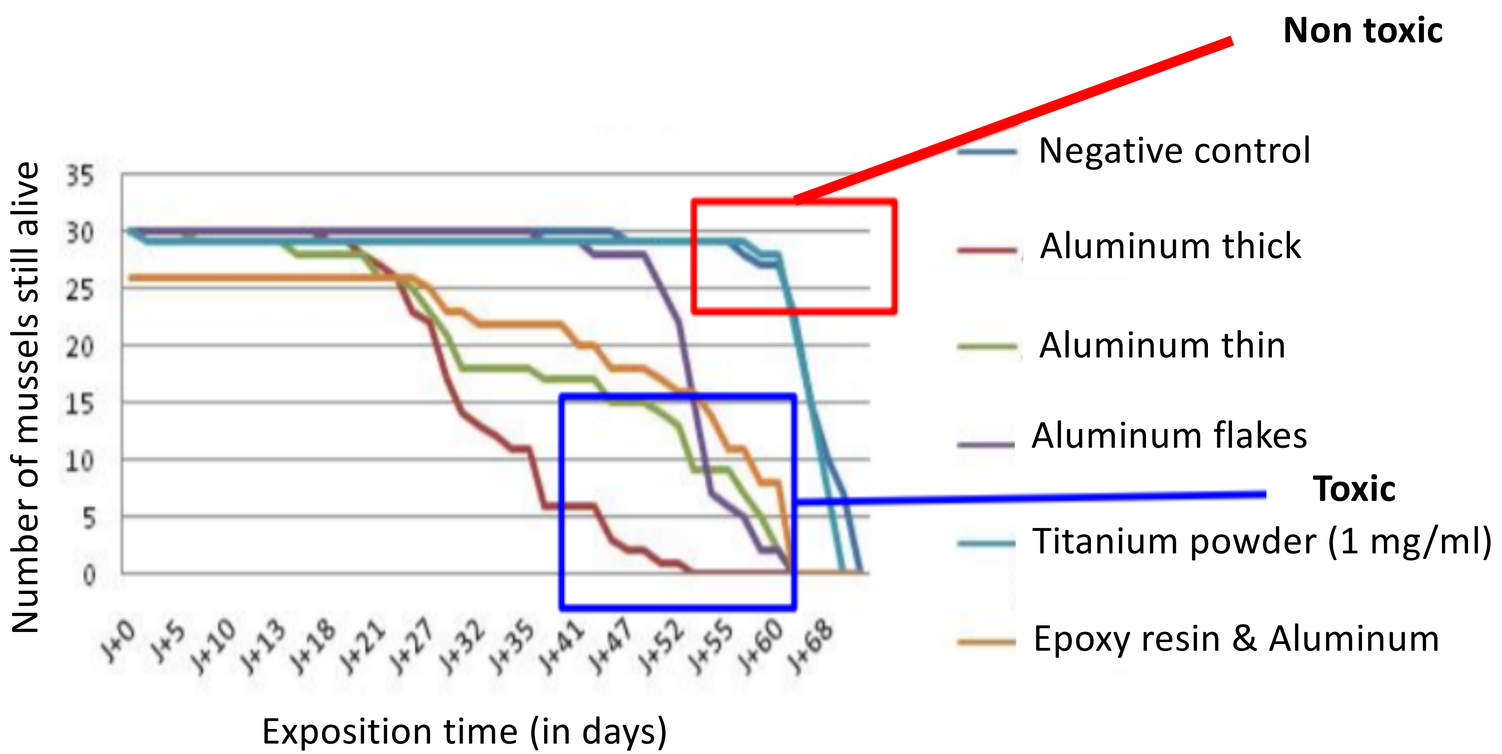
Graphiques représentants les concentrations en (ppb) de Fer dans l'eau de mer et dans les moules après un mois d'expérimentation.



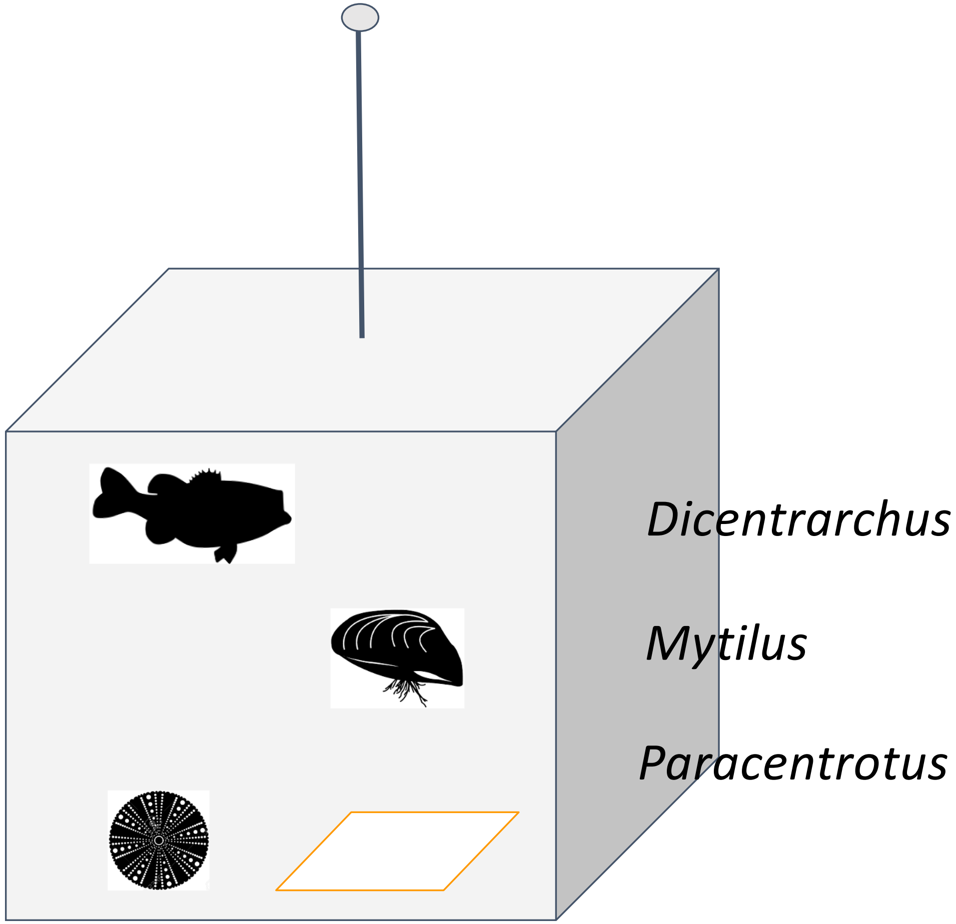
Graphiques représentants les concentrations en (ppb) de Fer dans l'eau de mer et dans les moules après un mois d'expérimentation.

Ecotoxicity evaluation

Macrofauna *in vitro* **Survival curve for mussels exposed to different metals**



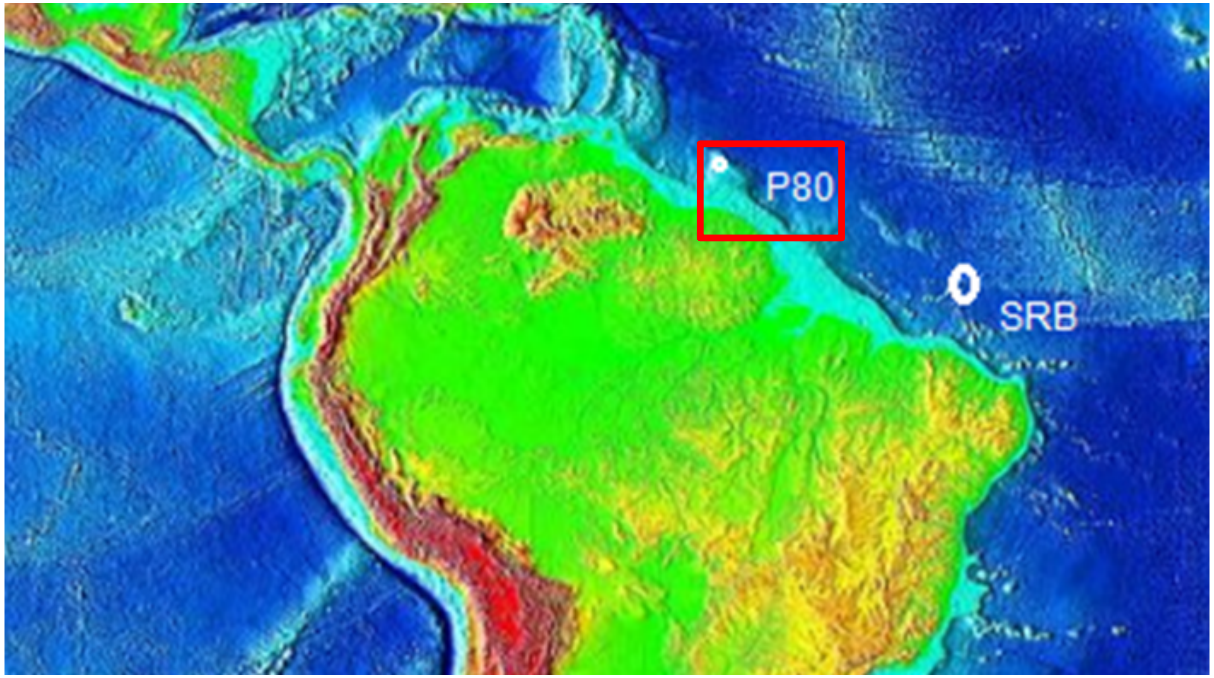
Ecotoxicological '*in situ*' assessements



IN SITU IMPACT STUDIES in French Guyana

esa
UNIVERSITÉ DE MONTPELLIER
fds FACULTÉ DES SCIENCES MONTPELLIER
Deloitte.
museum
HYDRECO GUYANE

Ecotoxicaligal assessments near French Guyana first stage falling point

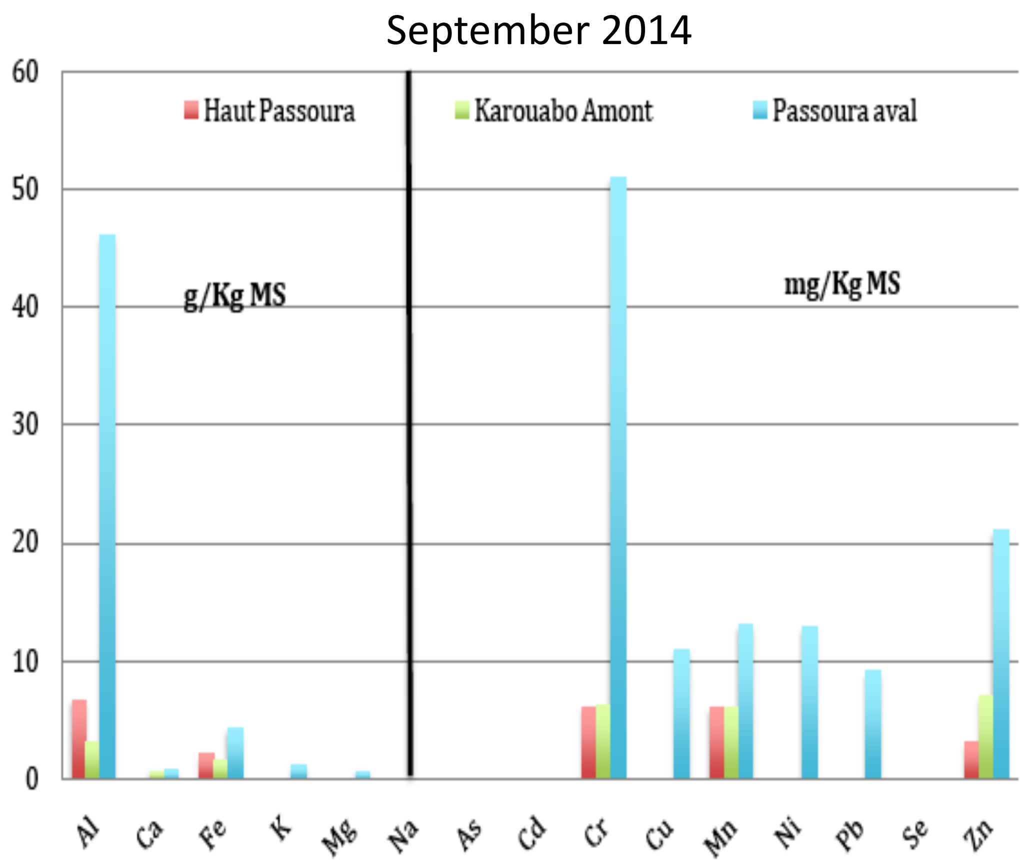


esa · Université de Montpellier · fds Faculté des Sciences Montpellier · Deloitte. · museum · Hydreco Guyane

IN SITU IMPACT STUDIES in French Guyana

In some locations, aluminum concentrations are high

Sediment status



Anthropogenic contaminations ?

IN SITU IMPACT STUDIES in French Guyana

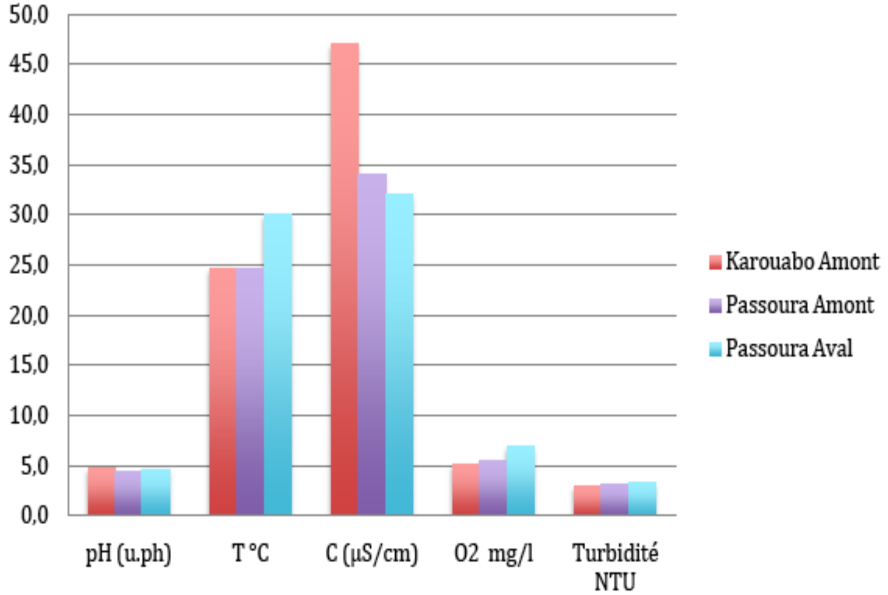
Water Quality

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

Fish populations

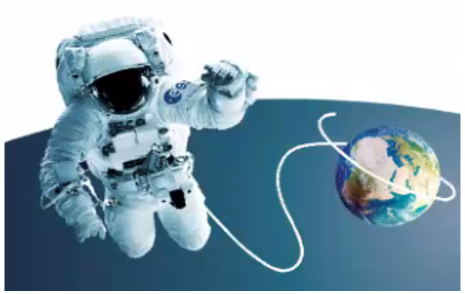
- Sites in good environmental health
- Strong imbalance in local fish population distribution (Vigouroux & Guillemet, 2006)

In situ measurements



However, 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



MELISSA
MICRO-ECOLOGICAL LIFE SUPPORT SYSTEM ALTERNATIVE

Conclusions & Perspectives

esa

UNIVERSITÉ DE MONTPELLIER

fds FACULTÉ DES SCIENCES MONTPELLIER

Deloitte.

museum

HYDRECO GUYANE

Conclusions & Perspectives

- Behaviour and toxicity of the different compounds carried out varry according to the substrate but also to environmental conditions (depth oxygen availaibilities)

- Exposure time must be taken into consideration and no 'rapid' conclusion can be driven from the available litterature

  => experimental approach used during the project

- Longer impacts need to be investigated

MELISSA
MICRO-ECOLOGICAL LIFE SUPPORT SYSTEM ALTERNATIVE
Deloitte.
Marianne Planchon
Augustin Chanoine
Regis Vigouroux
Jan Vanaverbeke
Steven Degraer
HYDRECO GUYANE
museum
THANK YOU.
C. Lasseur
esa
Stephanie Raffestin
www.melissafoundation.org
Follow us
Sophia Klink
Eymeric Fleouters
Benjamin Lemoing
Jehan Lignot
UNIVERSITÉ DE MONTPELLIER

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

Thank you for your attention !

UNESCO and France have formalized the creation in Montpellier of the International Centre for Interdisciplinary Research on Water Systems Dynamics (ICIReWaRD) which will provide expertise, carry out research and training actions in management and governance, of water science and technology in vulnerable regions, focusing in particular on problems linked to rapid urbanization, demographic pressure and the foreseeable effects of climate change.

UNIVERSITÉ DE MONTPELLIER

esa

fds FACULTÉ DES SCIENCES MONTPELLIER

Deloitte.

museum

HYDRECO GUYANE