



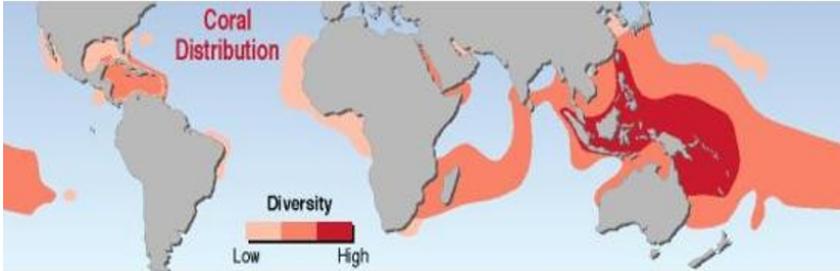
Alor, Indonesia
Credit: Erik Lukas

TOTAL R&D - SEABOOST

Déversement d'hydrocarbures en milieux tropicaux: Solutions d'écoconstruction pour la préservation et la restauration d'écosystèmes coralliens et de mangroves

STAKES FOR TOTAL

There are currently several TOTAL sites worldwide presenting a potential risk regarding degradation of coral reefs or mangroves ecosystems (EP, MS, GRP, RC):
e.g. Australia, Papua New Guinea, Qatar, U.A.E, Uganda / Tanzania, Brazil, French Guyana, Mayotte, Fiji, New Caledonia, Tahiti, etc.



From Mokili benchmark, 2017



Répartition des récifs coralliens du monde. <https://www.universalis.fr/encyclopedie/recifs-coralliens/>

Damaging the coral reefs is a real stake for local people and media, and a very sensitive communication subject → Potential risk for license authorization

Corail contre pétrole: pour sauver un récif au large du Brésil, Greenpeace simule une marée noire au siège de Total

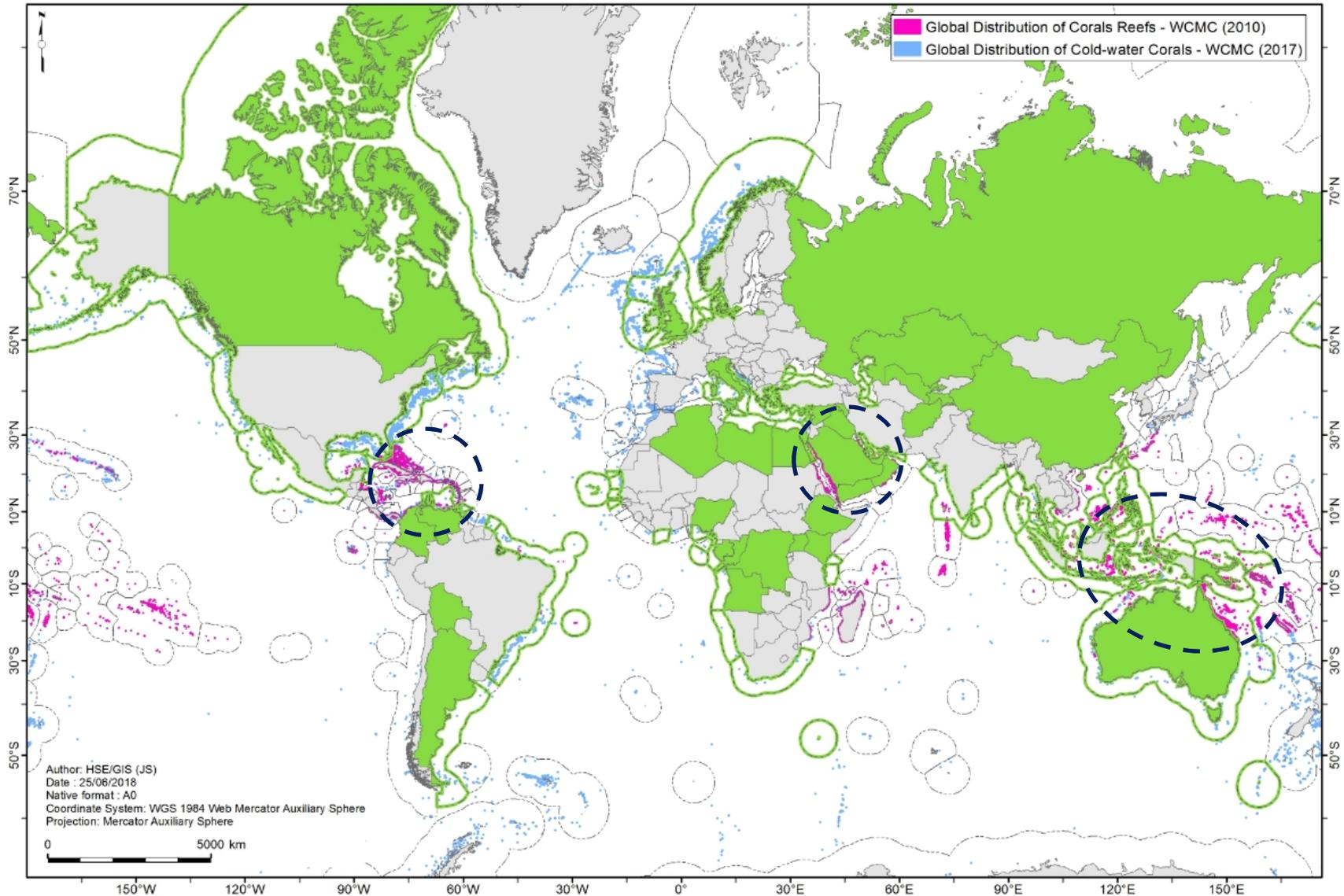


Des militants de Greenpeace ont déversé de la mélasse devant le siège de Total à La Défense, le 27 mars 2017, pour dénoncer un projet pétrolier à l'embouchure de l'Amazone. Photo AFP



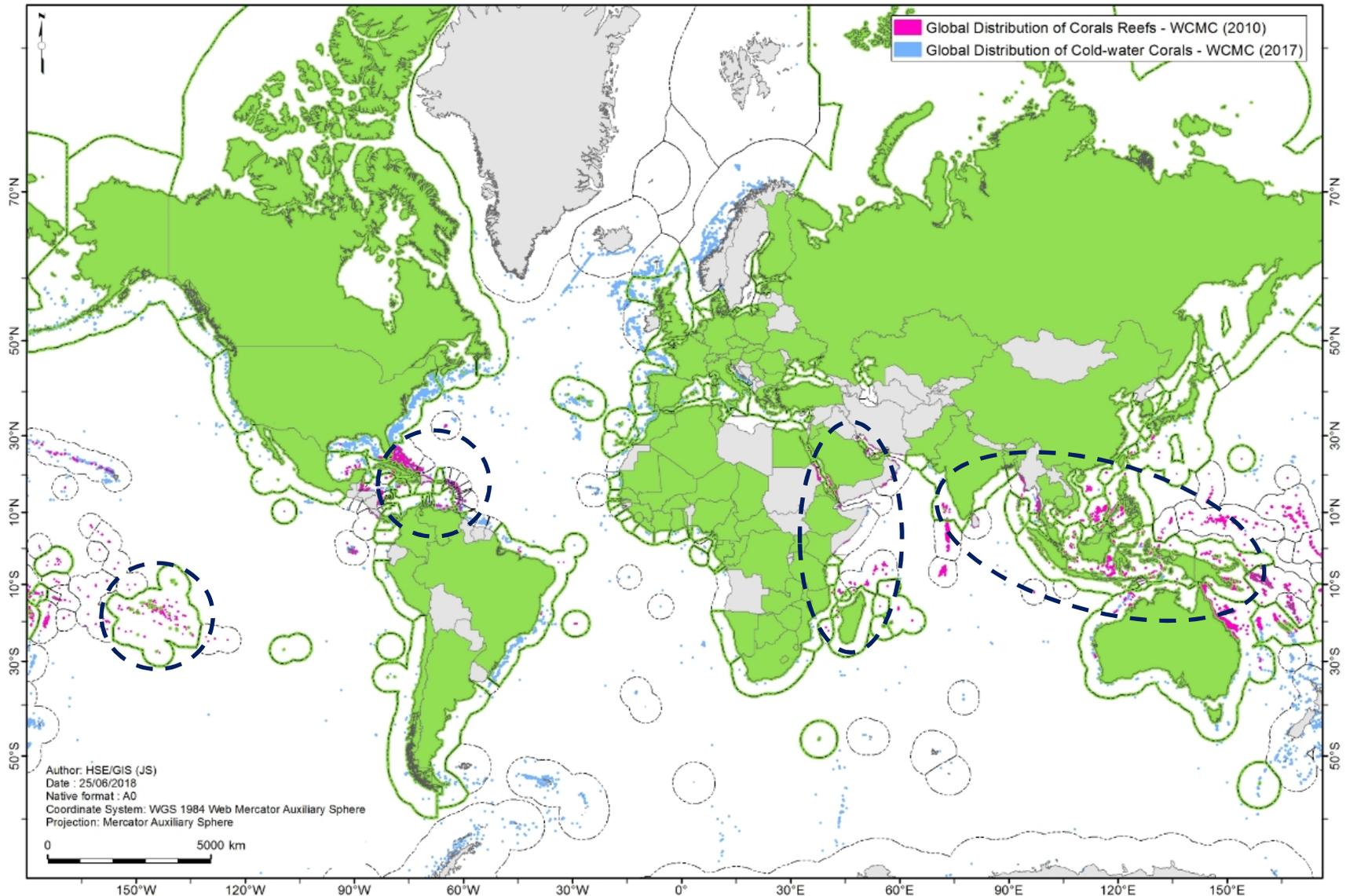
TOTAL PRESENCE VS CORAL REEFS: EP

WORLD CORAL REEF DISTRIBUTION - TOTAL E&P ACTIVITY BY COUNTRY (OPERATOR OR PARTNER)



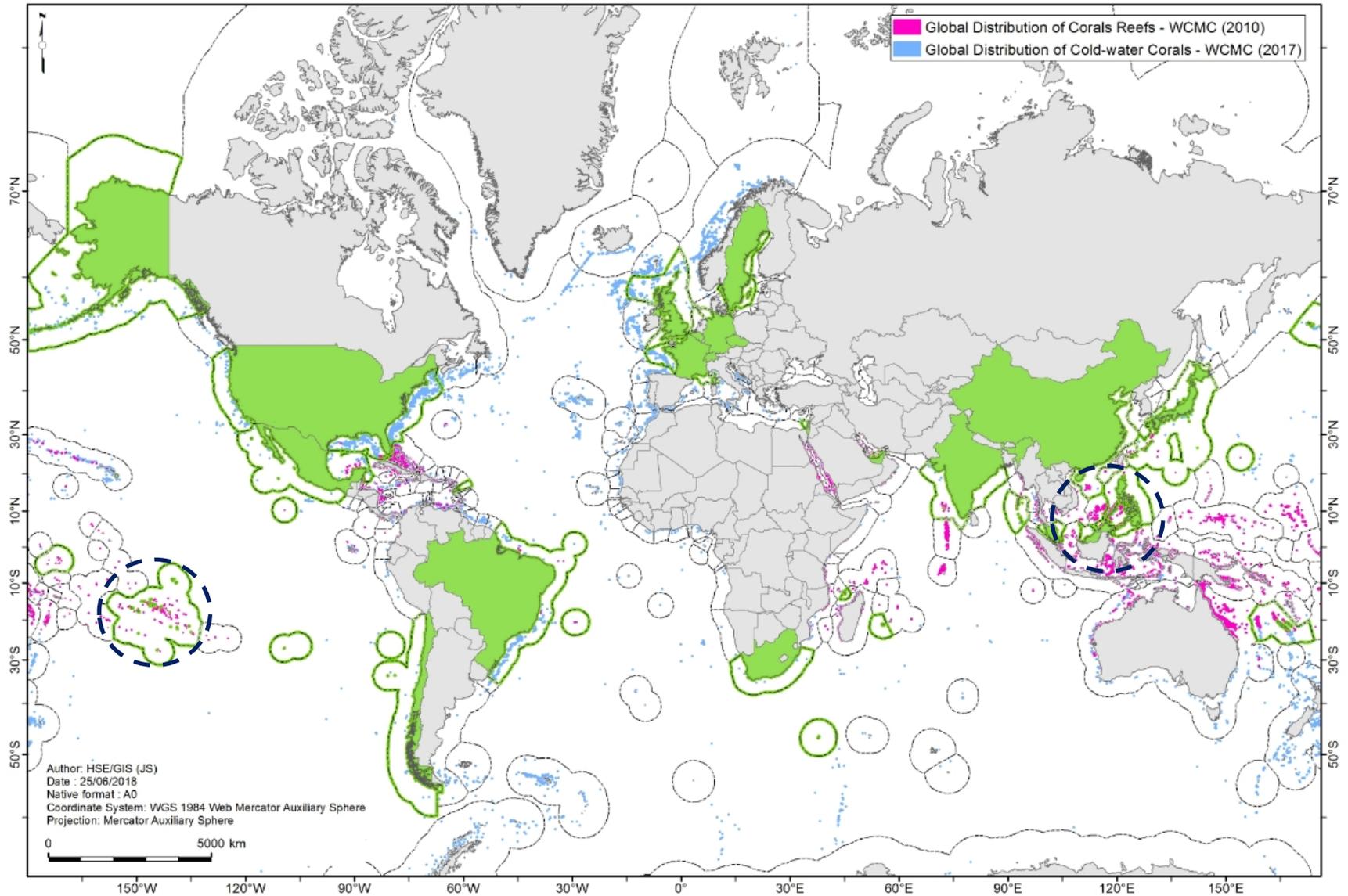
TOTAL PRESENCE VS CORAL REEFS: MS

WORLD CORAL REEF DISTRIBUTION - TOTAL MS SITES BY COUNTRY



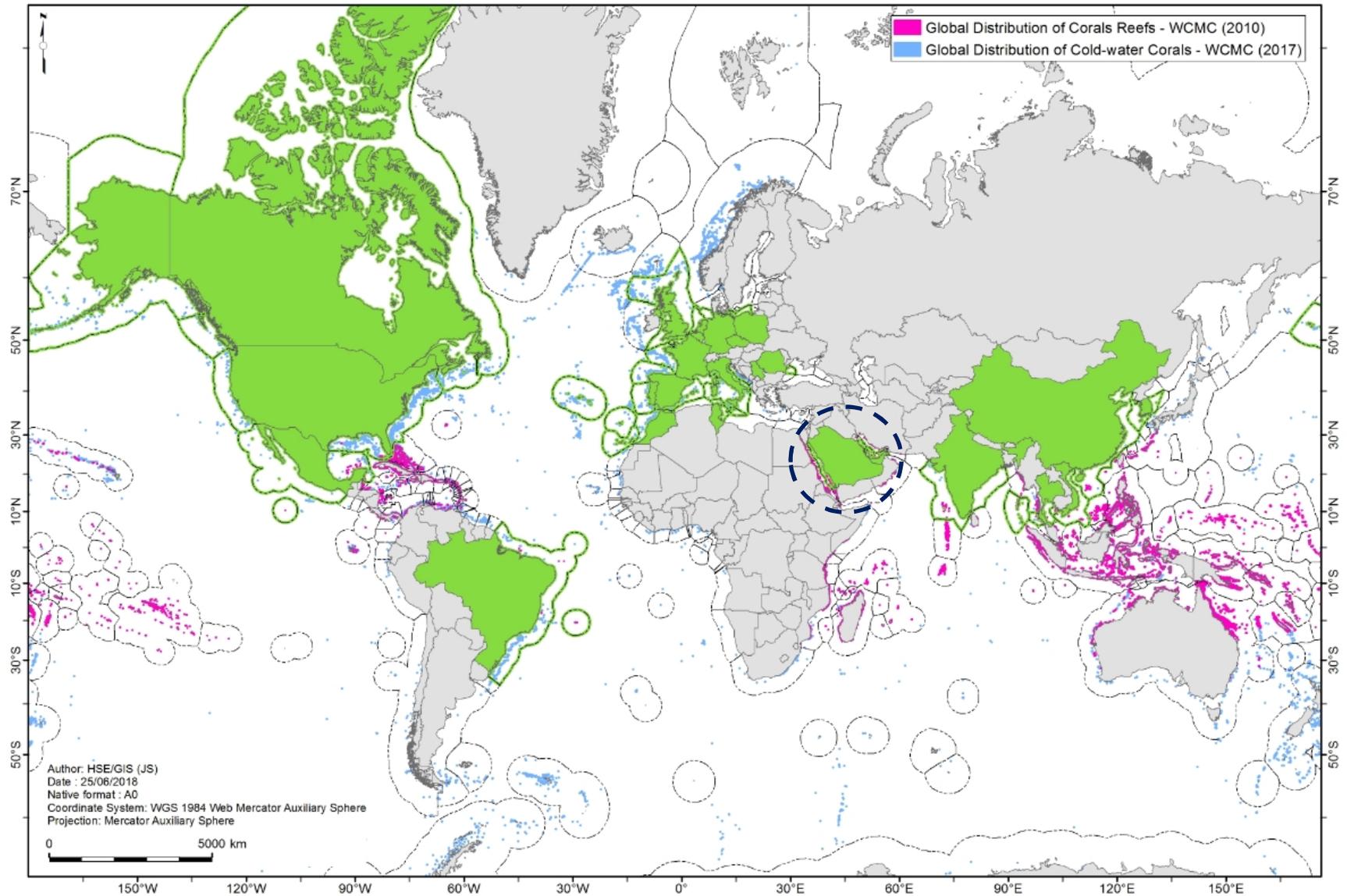
TOTAL PRESENCE VS CORAL REEFS: GRP

WORLD CORAL REEF DISTRIBUTION - TOTAL GRP SITES BY COUNTRY



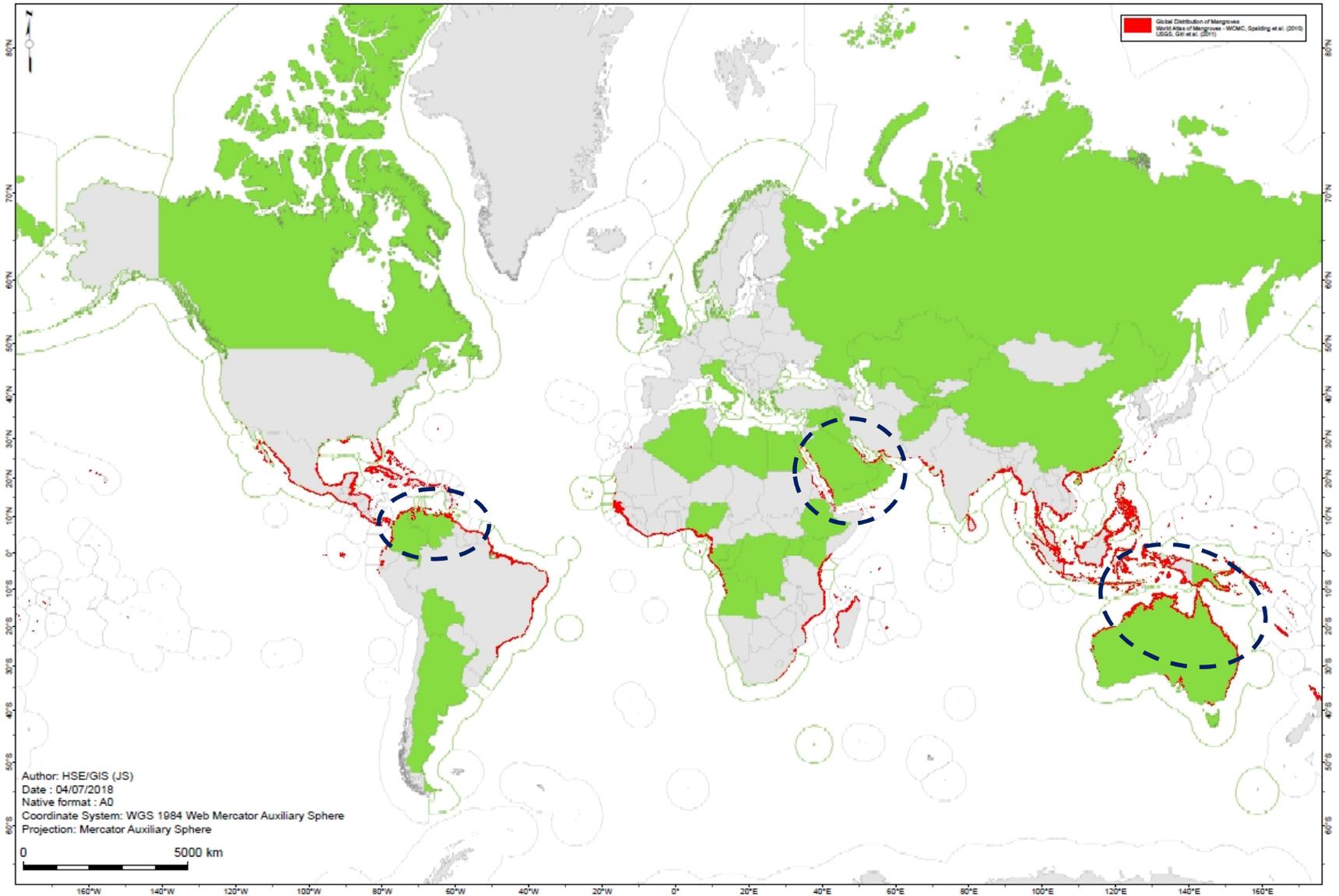
TOTAL PRESENCE VS CORAL REEFS: RC

WORLD CORAL REEF DISTRIBUTION - TOTAL RC SITES BY COUNTRY



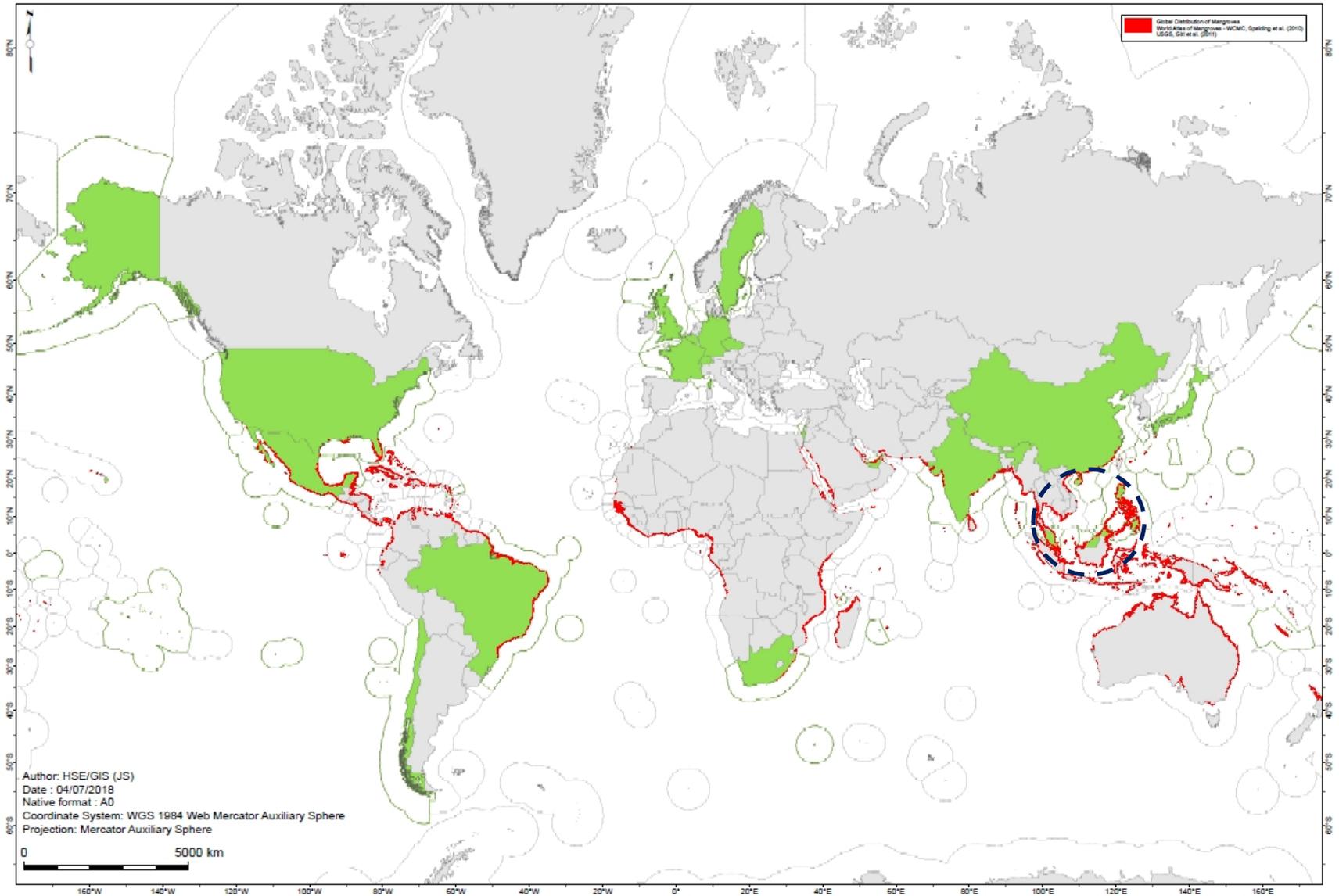
TOTAL ACTIVITY VS MANGROVES: EP

WORLD MANGROVES DISTRIBUTION - TOTAL E&P PRESENCE WORLDWIDE (OPERATOR OR PARTNER)



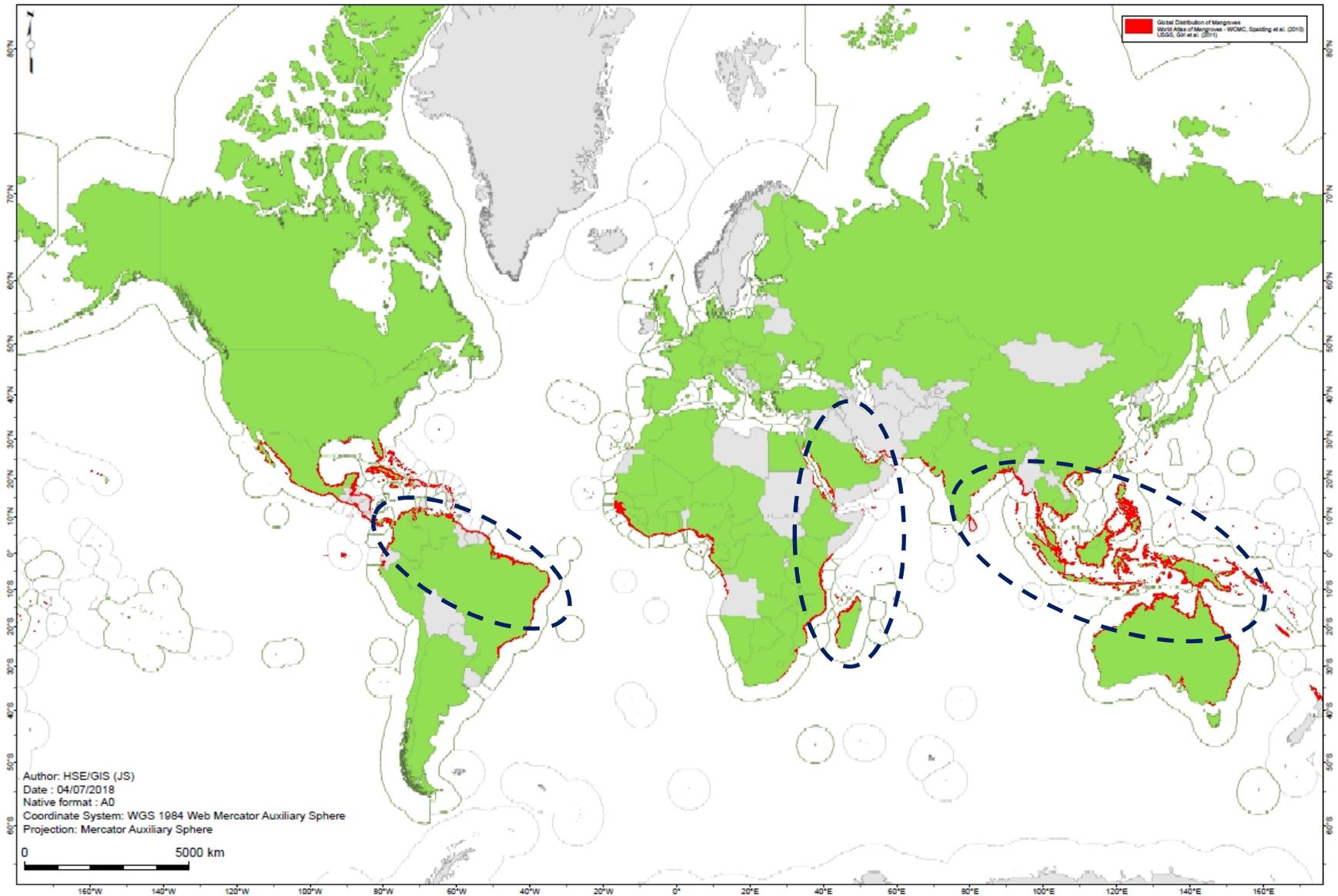
TOTAL ACTIVITY VS MANGROVES: GRP

WORLD MANGROVES DISTRIBUTION - TOTAL GRP PRESENCE WORLDWIDE



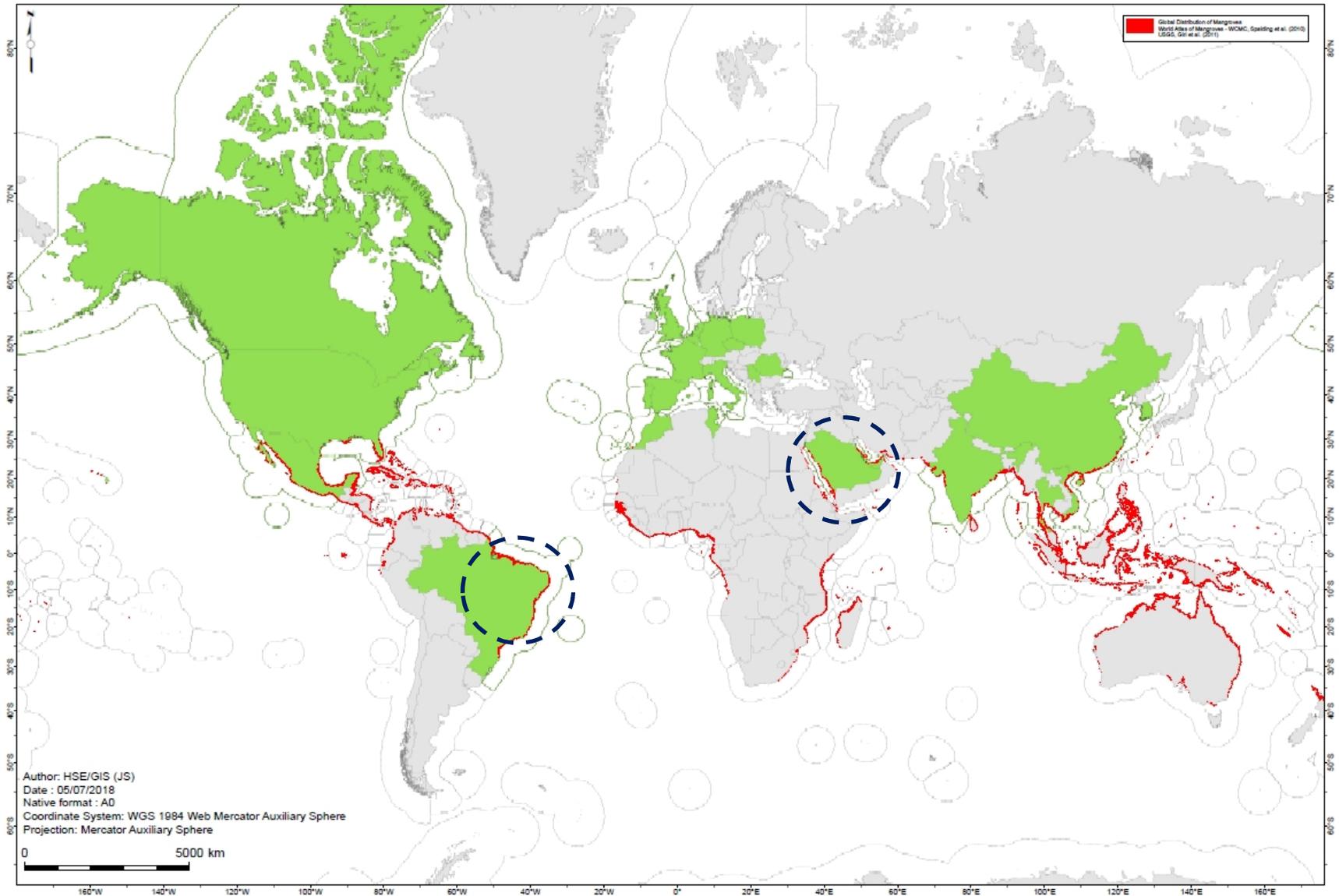
TOTAL ACTIVITY VS MANGROVES: MS

WORLD MANGROVES DISTRIBUTION - TOTAL MS PRESENCE WORLDWIDE



TOTAL ACTIVITY VS MANGROVES: RC

GLOBAL MANGROVES DISTRIBUTION - TOTAL RC ACTIVITY BY COUNTRY



ECOCONSTRUCTION - OVERVIEW OF HISTORY



2015 Opportunity study by Seaboost: application of ecological engineering and artificial habitat technology as innovative tools for the mitigation of the environmental effects of marine oil & gas activities

- Reef effect of offshore oil & gas infrastructure
- Existing tools and methods for the restoration of coastal habitats degraded by oil spills
- Innovative environmental indicators for the evaluation of environmental effects of offshore oil & gas activities.

2016 Gap analysis & Selection of R&D topics of interest

→ **Innovative restoration solutions for degraded marine tropical ecosystems**

- Mangroves
- Corals

2016-2017

Framing study by Seaboost: Feasibility study of 5 proposed solutions (ROOT, REEF, SHIELD, BOOSTER, CLEAN) - Definition of R&D projects for selected solutions

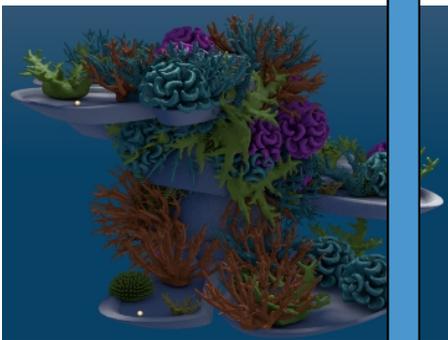


2017 Mission in Qatar (Oct.2017): Evaluation / Preparation of REEF demonstrator implementation project

Benchmark study by Mokili: Focused on REX and R&D on restoration solutions & initiatives on degraded mangroves and corals

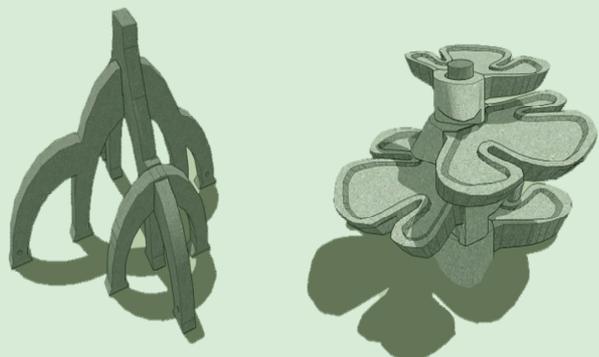
2018 Way forward:

- Preparation / Launching of QataREEF pilot (2018-2022)
- Launching of REEF RESEARCH phase I (2018-2020)
- Launching of ROOT RESEARCH phase I (2018)
- Project definition for ROOT DEMONSTRATOR



ECOCONSTRUCTION RESTORATION OF CORALS AND MANGROVES

5 SOLUTIONS COVERING A WIDE RANGE OF ECOLOGICAL AND SOCIETAL FUNCTIONALITIES



ROOT

Tool for a temporary substitution of key mangrove functions (habitat, swell attenuation, erosion control)

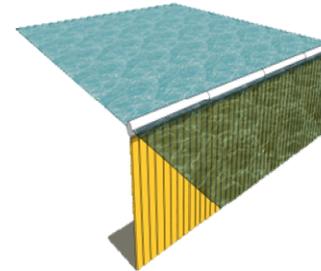
REEF

Tool for the enhancement of coral recolonization and reef rehabilitation



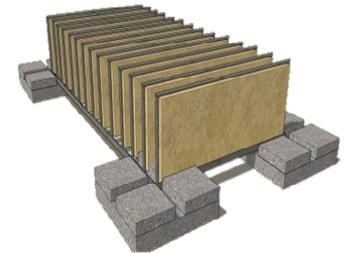
BOOSTER

Tool for long distance coral larvae attraction



SHIELD

Tool for oil capture in shallow coastal areas



CLEAN

Tool for water filtration and mitigation of chronic water contamination



CORALS: STATE-OF-THE-ART

REX Yemen: Corals Relocating (Transplantation) (construction operations)

- Time consuming
- Requires a team of scientific divers
- Safety risks associated with underwater operations
- Does not allow reconstruction of degraded ecosystem → Does not reduce habitat loss
- Not adapted to all coral species
- Spatial limitations



Plan of corals transplantation in Yemen

External benchmark (MOKILI)

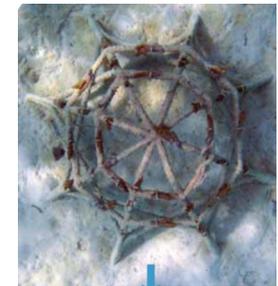
- Coral reef rehabilitation is still in its infancy
- Traditional approach: asexual approach (translocation / coral gardening)
- Very few examples of use of artificial structures, with limited success in space and time
- 1 alternate tech. by electro-accumulation (Biorock), no evidence of growth and survival efficiency in time



Reefscapers, local company working with hotels in Maldives to restore/create coral reefs (2005-2017)



Biorock: Limestone 1-year deposit on a steel bar in Maldives (source: Goreau, 2012)



Coated metal frame in Maldives in 2005

Concrete pipe modules in Thailand (Phuket; 1994-2007)

CORALS: STATE-OF-THE-ART

External benchmark (MOKILI)

- Emerging technology: 3D printing of artificial structures
- Conclusion:
 - Coral remediation is mostly being developed for non-oil related impacts (including sea warming, tourism)
 - Coral remediation is still done using very classic techniques
 - Artificial structures are simple objects not maximizing marine life
 - Efficiency limitations in time and space, depending on budget allocation



Reef prints (sources: media on OLC & Coralise project)



Example of 3D printing of coral (taken from 3Dprintingindustry.com website)

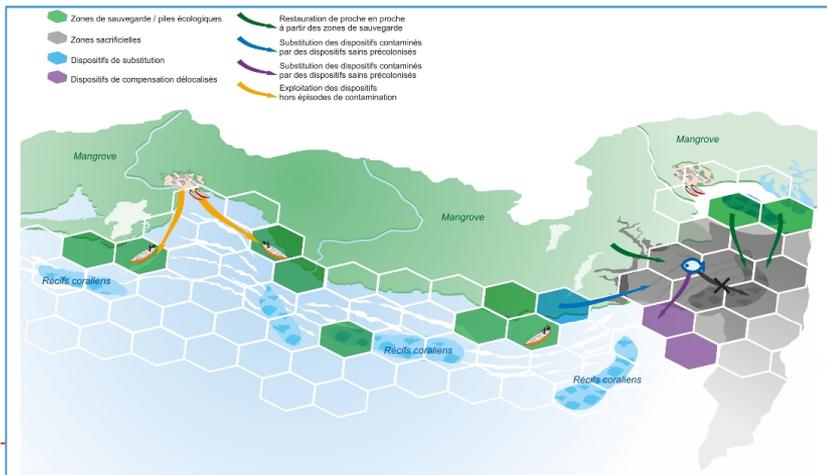
New approach: larval rearing (sexual approach)

SEABOOST state-of-the-art & framing study

- Restoration philosophy: Connectivity / mesh notion, sacrificial / sanctuary zones, substitution zones, ecological booster, relocalized offset...
- REEF solution: Biogenic innovative materials and movable structures to attract planulae larvae and boost coral reefs recolonization
- Societal benefits



Coral gamete collection using spawning nets (source: R. Ben Hamadou; QU, RESTORE KoM)



The SEABOOST REEF technology aims to address one of the major existing gap in coral restoration today: the lack of realistic (cost / operations) solutions to restore natural coral colonies sustainably and at a wide scale

REEF TECHNOLOGY PRESENTATION (1/3)

- **Concept:** A booster for coral recolonization of degraded marine areas at a large temporal and spatial scale (connectivity)
- **Object:** An artificial structure integrating specific materials with a specific design and physical and chemical properties for inducing coral recruitment and development
- **Use:** A “passive” but displaceable device
 - Phase 1 : Deployment of REEF units next to healthy corals that serve as « donors » (network) → REEF is progressively colonized by local coral species
 - Phase 2: REEF units are moved to degraded areas which need to be restored → REEF serves as a “donor” by disseminating larvae locally
 - Phase 3: Large impacted areas are re-colonized by connectivity
- **Innovations :**
 - Optimized Design: structural criteria for positive influence on settlement and growth of coral larvae (*multi-orientation, resilience to silting, water flow, variable exposure to light...*)
 - Optimized Materials: micro-structural and chemical characteristics for positive influence on settlement and growth of coral larvae (*porosity, pH, roughness,...*)
 - Deployment strategy / Movability: the device will be movable so that it can be used to enhance gamete emission as close as possible to restoration areas

TRL = 2-3
Objective of pilot → 4



[REEF animation](#)

REEF TECHNOLOGY PRESENTATION (2/3)

- **Design**

- Fractal geometry
- Asymmetric piles
- Grid-shell technology & claddings



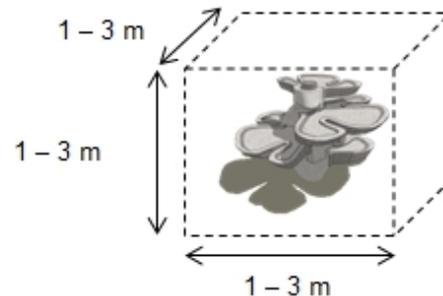
- **Materials :**

- Biogenic concrete
- Ceramic
- Composite materials



- **Volume : 3 – 15 m³**

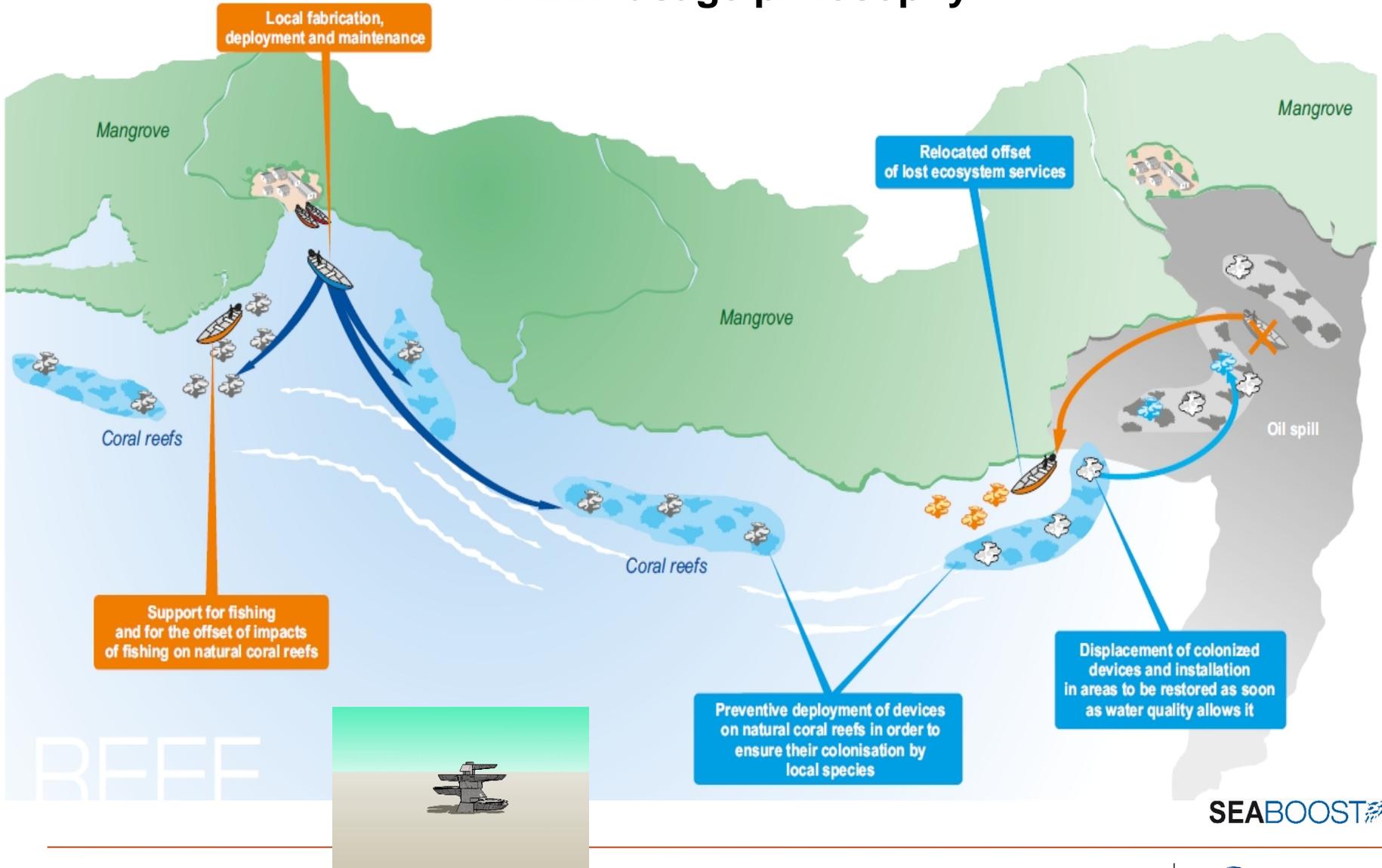
- **Weight : 2 – 5 tons**



[3D printing video](#)

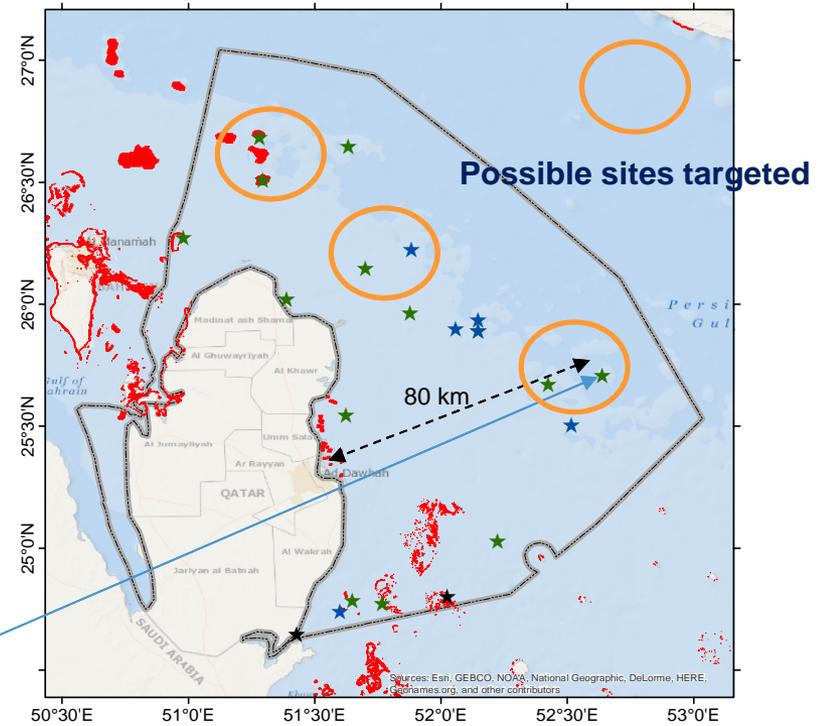
REEF TECHNOLOGY PRESENTATION (3/3)

REEF usage philosophy

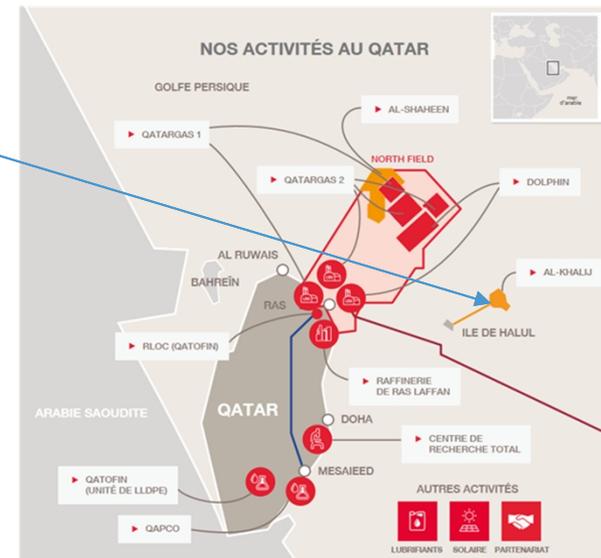


QATAR PILOT (“QATAREEF”)

- **Location:** Qatar, Arabic gulf (see plan)
- **18 REEF Units**
- **3 different sites**
- **3 replicates + 3 movable units / site**
- **If possible, one operational site: Halul Island terminal (pending QP approval)**
- **Water depth ca. 10-20m**
- **Duration of immersion: Q2 2019 – Q2 2022**
- **Main actors: Total R&D / Seabost / TRCQ / QU**



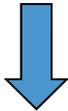
Halul Island crude oil export terminal (Qatar Petroleum)



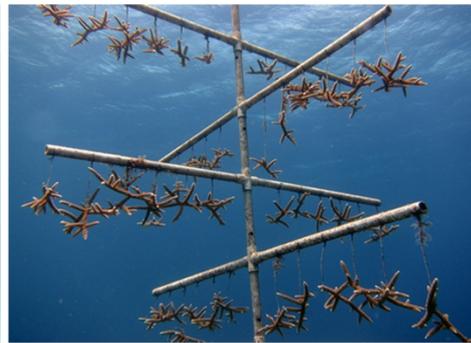
REEF RESEARCH

Action with Seaboost, and CRIOBE as a sub-contractor (2018-2020)

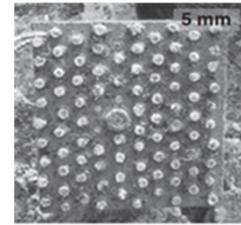
Object: R&D work to define best properties of porosity, roughness, and incubation needs of an artificial substrate in the natural environment, in order to optimize the installation and survival rate of coral colonies (in quantity and diversity)



Includes in situ tests on materials, and immersion tests of structures in the lagoon of Moorea (mini. 9 months)



Illustrations d'arbre à corail, structure utilisée comme nurseries pour les coraux. Ces structures favorisent la croissance des coraux par l'exposition au flux d'eau et le balancement.



(Doropoulos et al., 2016)



(Mallela et al., 2018)



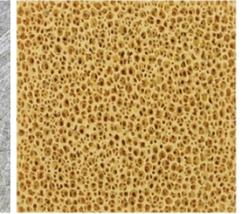
Béton à porosité contrôlée BBC



Béton à porosité contrôlée Hydromédia



Polymère fibre de verre



Mousse de céramique

Illustrations de plusieurs pistes de matériaux à tester

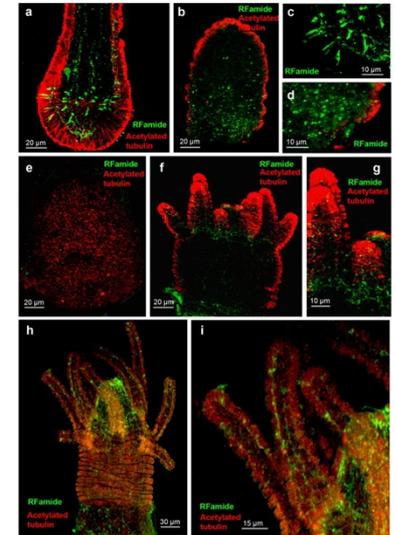
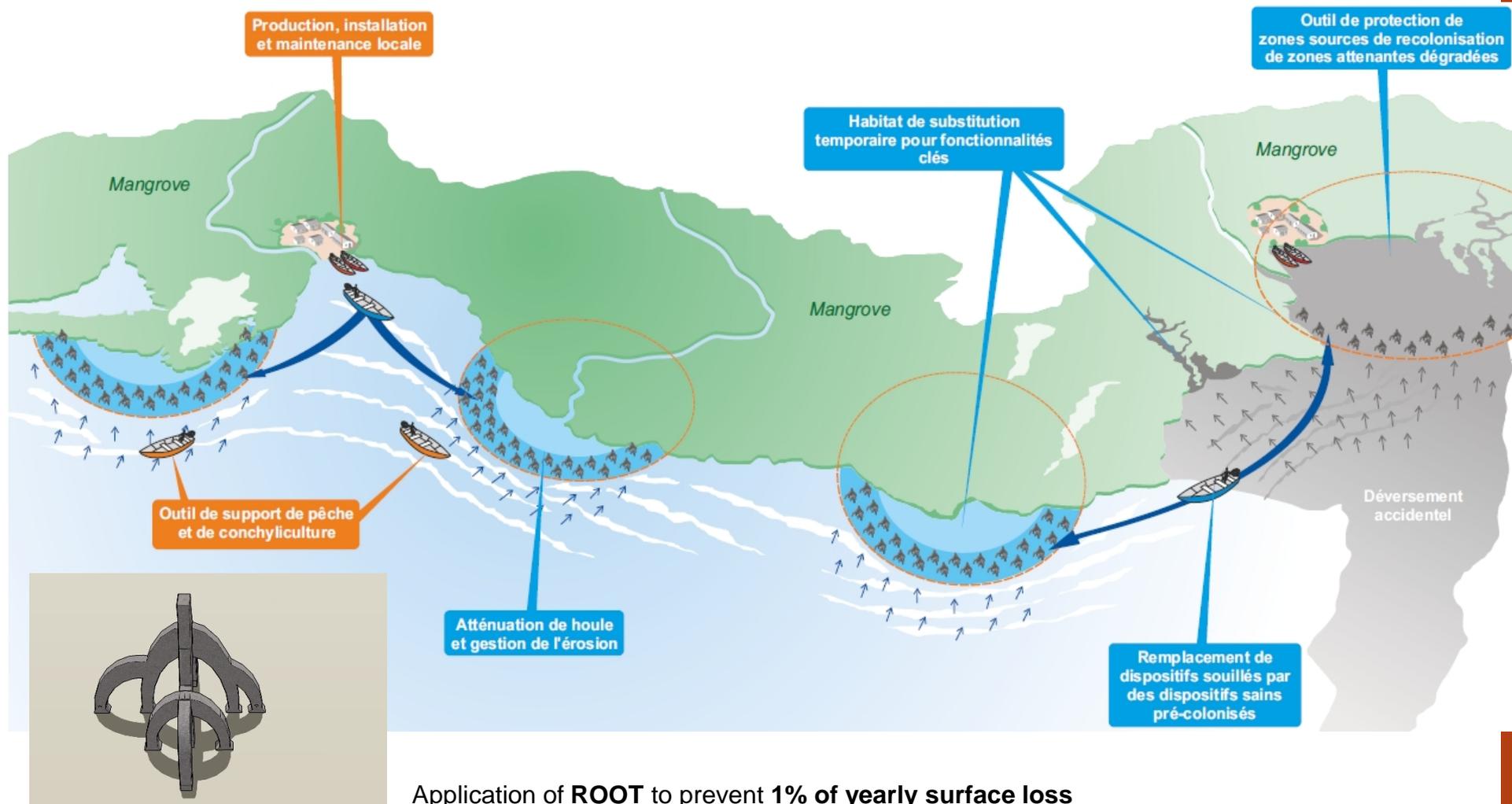


Illustration de l'observation de planulae coralliennes par fluorescence

ROOT CONCEPT – DEPLOYMENT STRATEGY



Application of **ROOT** to prevent **1% of yearly surface loss** would help to maintain stock and capture of **0.01 to 0.1 GTCO₂ EQ yearly** over a 10-year period which is **consistent with Argentina or Belgium annual total carbon emissions**

[Animation ROOT](#)

ROOT RESEARCH

R&D action with Seaboost (Centrale Marseille and IRD as actors)

Object: Experimental laboratory studies to define:

- Best physical conditions to restore degraded mangroves naturally (hydrodynamics, sediment dynamics, substrate...)
- Best construction properties to influence significantly these parameters (design, geometry, dimension, plasticity, ...)
- Best implementation scheme (deployment scheme, mooring, ...) in order to boost restoration significantly and sustainably while maximizing local appropriation (deployment, management, maintenance, usage...)

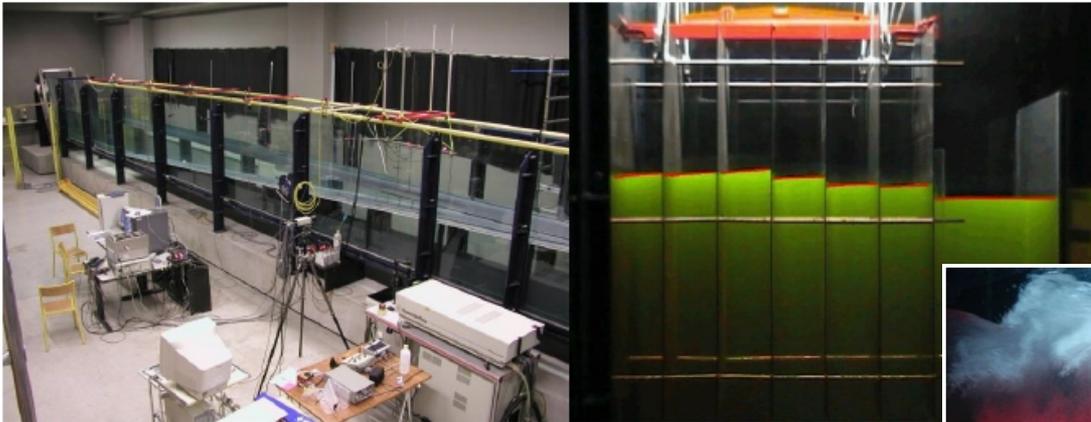
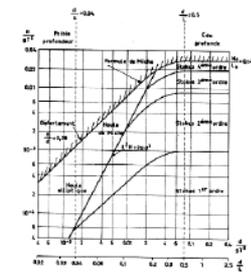


Illustration de manipulations en canal à houle (©Centrale Marseille)



Illustration du déferlement et de l'extraction graphique d'une expérimentation d'atténuation de houle menée en canal.



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