Assessing the ecological and social performances of Artificial Reefs

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Thanks to [MPA news], Octo group and Sarah ;-)

We are delighted to share within our world Community 20 years of research on AR

Who are we ?

Dr Sylvain PIOCH, assoc. Prof., Montpellier 3 Univ., Coastal Planning and Geography.

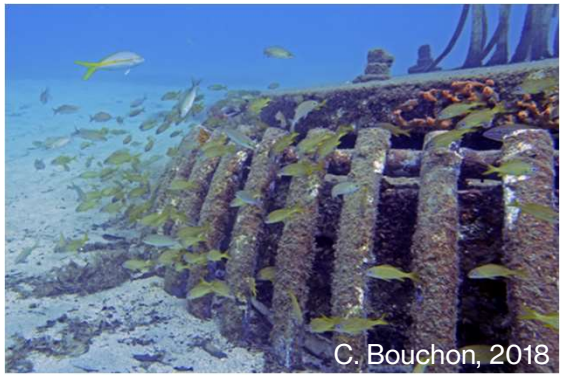
Key words: Environmental Impact Assessment, Ecological Ingineering (Artificial Reefs, Nature Based Solution, Eco-design, Rapid Assessment Method), Citizens participatory, Project co-design

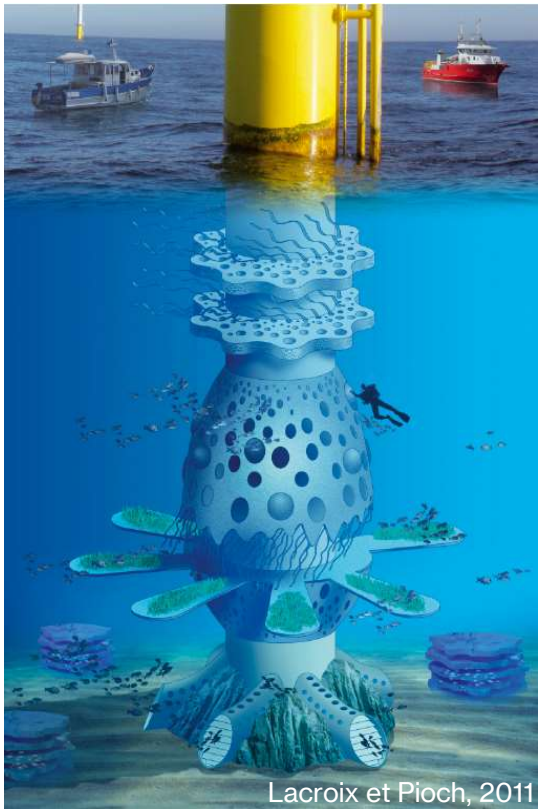
Research since 2003 (21 yrs), > 40 scient. publications on ecological eng. & AR. Example for 2023-2024:

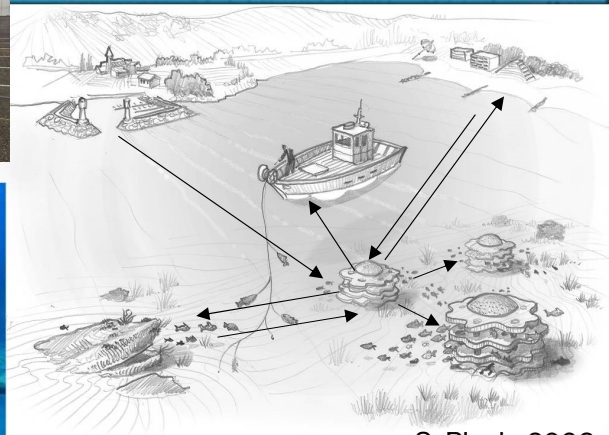
1. *Pioch, S., Patterson III, W. F. (2024). Mapped US artificial reef footprint.* ***Nature Sustainability****, 7(2), 100-101.*
2. *Firth, L. B., Bone, J., Bartholomew, A., Bishop, M. J., Bugnot, A., Bulleri, F., Chee, Pioch S. et al., (2024). Coastal greening of grey infrastructure: an update on the state-of-the-art. In* ***Proceedings of the Institution of Civil Engineers-Maritime Engineering*** *(pp. 1-69). Emerald Publishing Limited.*
3. *Salaün, J.*, Raoux, A., Pezy, J. P., Dauvin, J. C., Pioch, S. (2023). Structural and functional changes in Artificial Reefs ecosystem stressed by trophic modelling approach: Case study in the Bay of Biscay.* ***Regional Studies in Marine Science****, 65, 103100.*
4. *Hayek M., Salgues M., Souche J.C., De Weerdt K., Pioch S. (2023). How to Improve the Bioreceptivity of Concrete Infrastructure Used in Marine Ecosystems? Literature Review for Mechanisms, Key Factors, and Colonization Effects.* ***Journal of Coastal Research*** *39:2. https://doi.org/10.2112/jcoastres-d-21-00158.1*
5. *Salaün* J., Raoux A., Pezy J.P., Ferrou-Rocher A., Pioch S., Dauvin J.C., (2023). Ecosystem-Based Management approach applying to Artificial Reefs assessment: a case study of network analysis in Capbreton, France. La Mer,* ***Japanese-French Oceanographic Society Bulletin****; 61 (1-2).*
6. *Pioch S., Souche J.C. (2023). Écoconception des ouvrages maritimes : de la théorie aux exemples appliqués.* ***Techniques de l'Ingénieur****, GE 1 024, pp. 1-21. https://doi.org/10.51257/a-v1-ge1024*
7. *Léocadie, A., Pioch, S., Pinault, M., David, G. (2023). Efficacité de la restauration écologique en milieu marin tropical: revue critique dans l'Océan indien.* ***Caribbean's studies****, (53).*
8. *Etc.*

AR experiences in deployment and assessment

- 13 AR projects as director or expert
- ~ 600 AR submerged



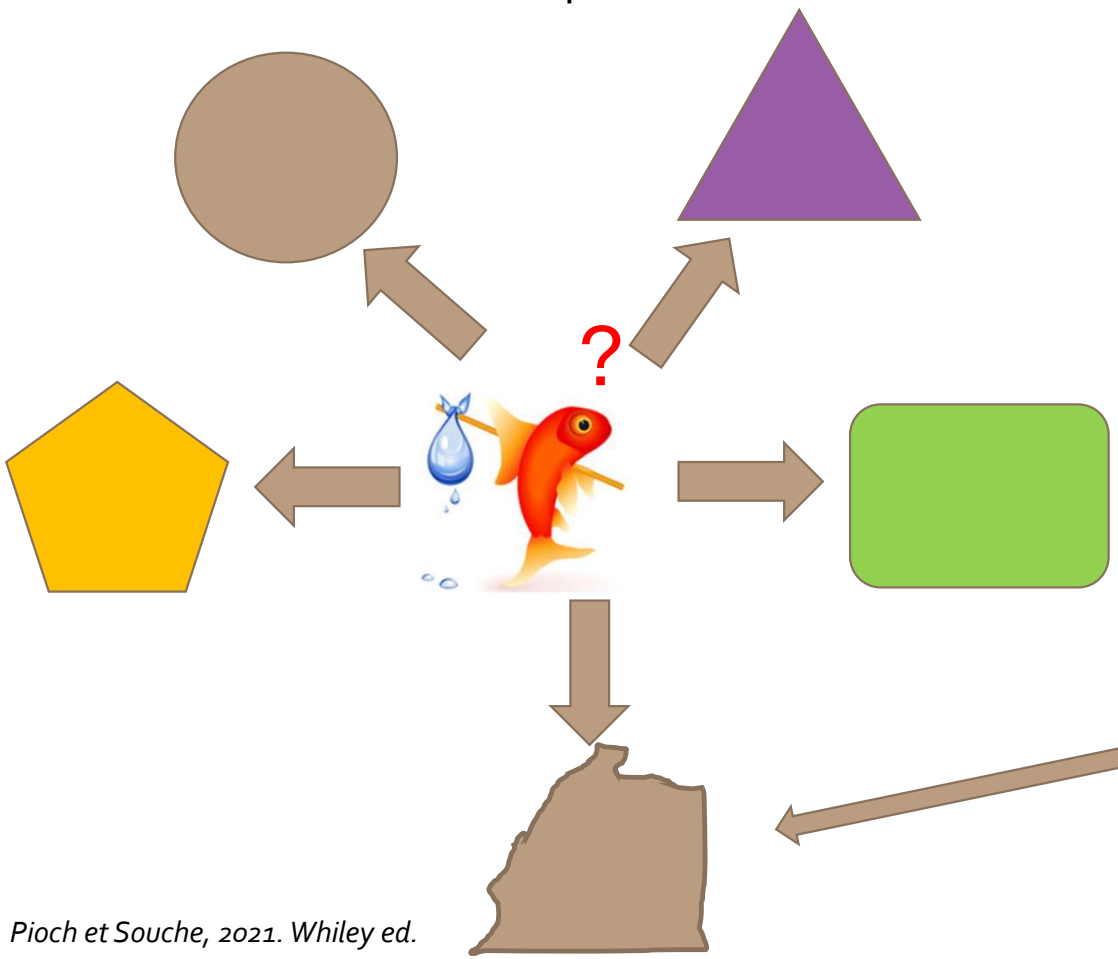




S. Pioch, 2008

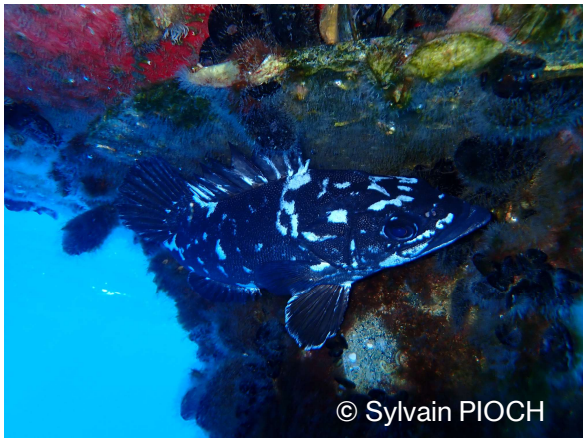
Main research results « *of interest* »

- Wich house for wich species ?

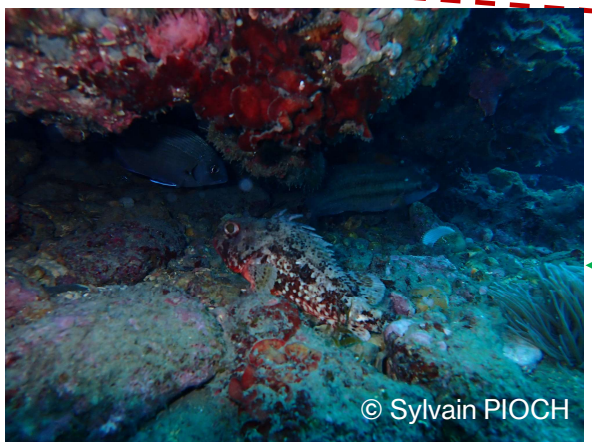


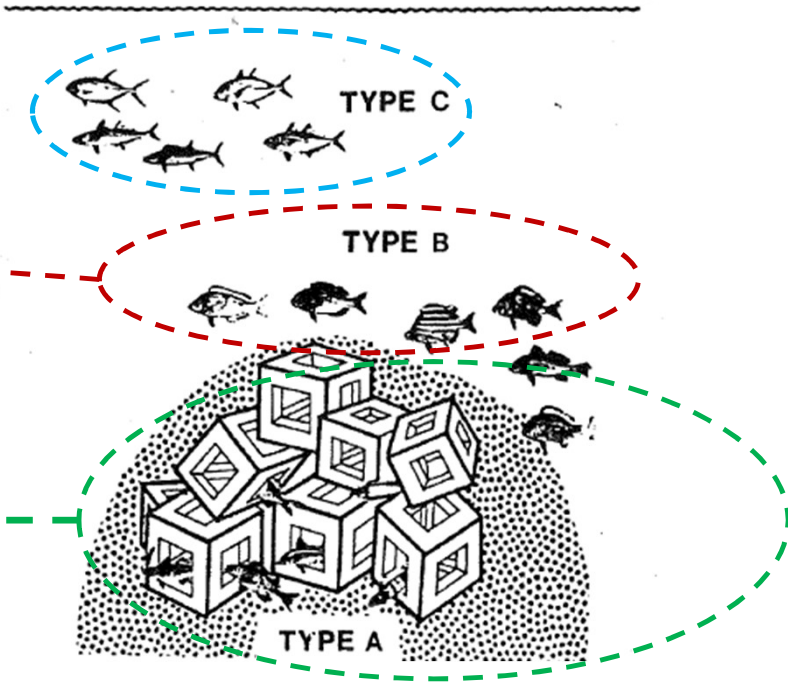
Pioch et Souche, 2021. Whiley ed.

Ethological relationship between fishes and natural habitat



Targeted species and macro dimensional design





Pioch et al. (2018). Enhancing eco-engineering of coastal infrastructure with eco-design. ***Ecological Engineering***, *120*, 574-584

Pioch et al. (2011). In "Artificial reefs in fisheries management". Bortone, S. A., Brandini, F. P., Fabi, G., & Otake, S. (Eds.). (2011). ***CRC Press****.*

Nakamura, M. (1985). Evolution of artificial fishing reef concepts in Japan. ***Bulletin of Marine Science****, 37(1), 271-278.*

Translate into AR design

Types of target species	Behaviors	Natural habitats sought	Adapted AH categories	Complexity of the eco-designed module			Species requirement
A	Benthic Low displacement Local scale	Hard substrates with dark and complex cavities	1	Numerous and complex shelters	Low cavity height ≥ target species	Internal spaces close to the size of benthic species (narrow, often cryptic cavities)	Majority or part of the body in contact with the artificial habitat
B	Demersal Medium to large displacement Regional and national scale	Hard substrates with medium to large cavities	2	Low complexity shelters	Average cavity height > target species height and width	Internal spaces large enough for demersal fish to visually identify themselves fully and move through cavities without coming into contact with the AH	Little physical contact with the artificial habitat but swimming in the vicinity
C	Pelagic Major migratory movements International scale	Open water and the proximity of steep or very steep upwelling	3	No shelters	Greater or lesser cavity height	Shape creating current disturbances and/or a position between the surface and the middle of the water column above the mean thermocline	Away from the AH and living in open water

Table 3.4. *Relationship between target species types and eco-design (S. Pioch)*

Pioch et Souche, 2021. Whiley ed.

Catalog of design & target (> 300 mod.)

Modèles		Dimensions (m)				Volume total m 3	volume disponible m 3	Poids T	Catégorie / espèces cibles	Juvéniles	Adulte
		L	l	ø	h						
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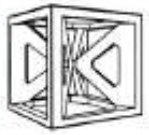
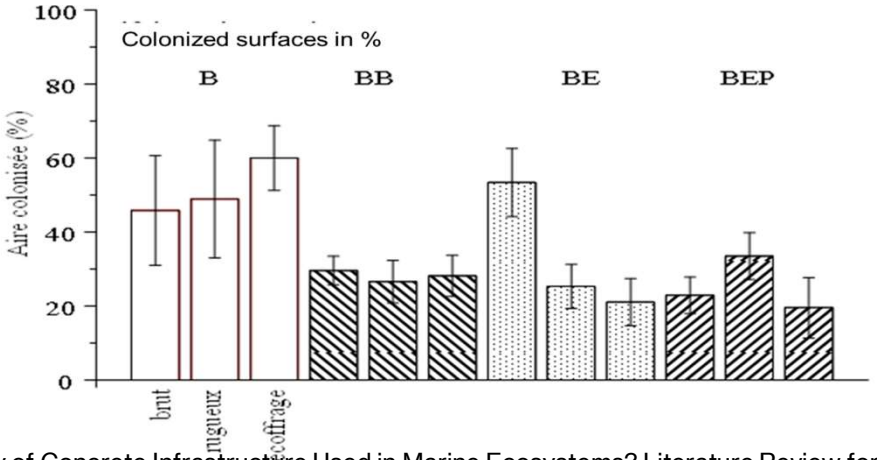
		5	5		5	125	100	43	2 / B	-	X
		17 ;5	17,5		20		1 285	79	3 / C	-	X
		12	11		21		405	49	3 / C	-	X
		5	5		1,7	42,5	32	19,5	1 / A	-	X

S. PIOCH, 2008

Colonization with « Bio » concrete and structural experiences

Factors studied:
- Surface pH
- Cement component (oyster / fertilizer…)
- Hydrofobicity
- Roughness

Results:
1. Little additional value with pH, cement compo. or hydrofobicity
2. Strong effet of level of roughness (surface state)



Lagune Palavas

Hayek, M., Salgues, M., Souche, J. C., De Weerdt, K., & Pioch, S. (2023). How to Improve the Bioreceptivity of Concrete Infrastructure Used in Marine Ecosystems? Literature Review for Mechanisms, Key Factors, and Colonization Effects. ***Journal of Coastal Research***, *39*(3), 553-568.

Hayek, M., Salgues, M., Habouzit, F., Bayle, S., Souche, J. C., De Weerdt, K., & Pioch, S. (2020). In vitro and in situ tests to evaluate the bacterial colonization of cementitious materials in the marine environment. ***Cement and Concrete Composites****, 103748*

Rapid Assessment Method to score gain of biodiversity

Need to assess and score the ecological performances of AR :

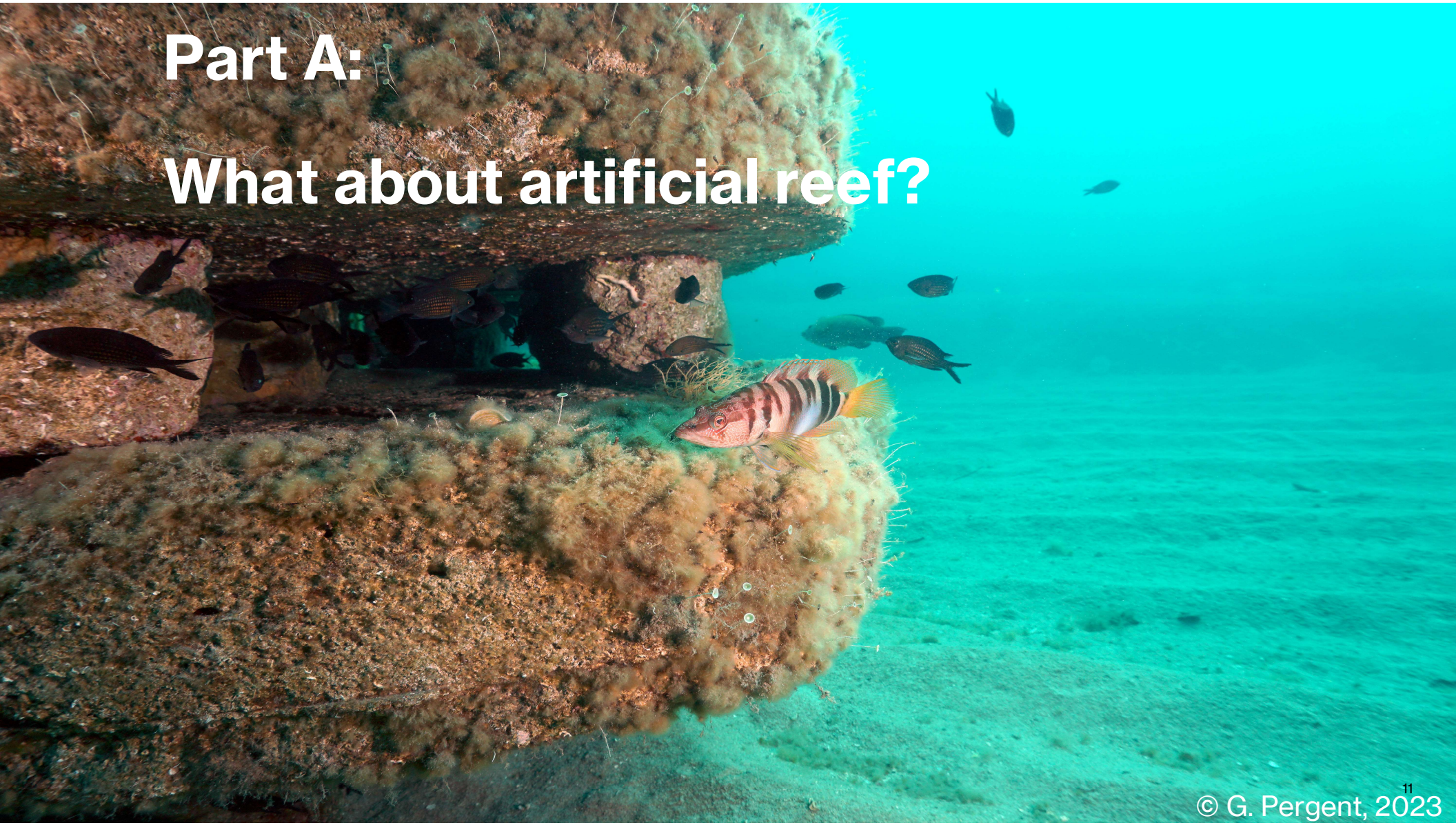
- Quickly
- Simple indicator to be understood
- Minimal cost

Pioch et al., 2018

https://icriforum.org/new-report-methodology-for-scaling-mitigation-and-compensatory-measures-in-tropical-marine-ecosystems/

Part A:

What about artificial reef?



Definition (FAO, 2015)

What is it:

"*An artificial reef is a submerged (or partly) structure* ***deliberately placed*** *on the seabed* ***to mimic some functions of a natural reef****, such as protecting, regenerating, concentrating and/or enhancing populations of living marine resources.*

It will ***serve as habitat that functions as part of the natural ecosystem*** *while doing 'no harm'.*"

What it is not:

"*The term* ***excludes*** *artificial islands, cables, pipelines, platforms, mooring, and structures for coastal defence (e.g. breakwaters, dikes, etc.) which are primarily constructed for other purposes,* ***as well as the fish aggregation devices (FADs)*** *employed to merely attract fish in certain fishing areas.*"


S. Blouet, AGDE

Original concept: historical roots

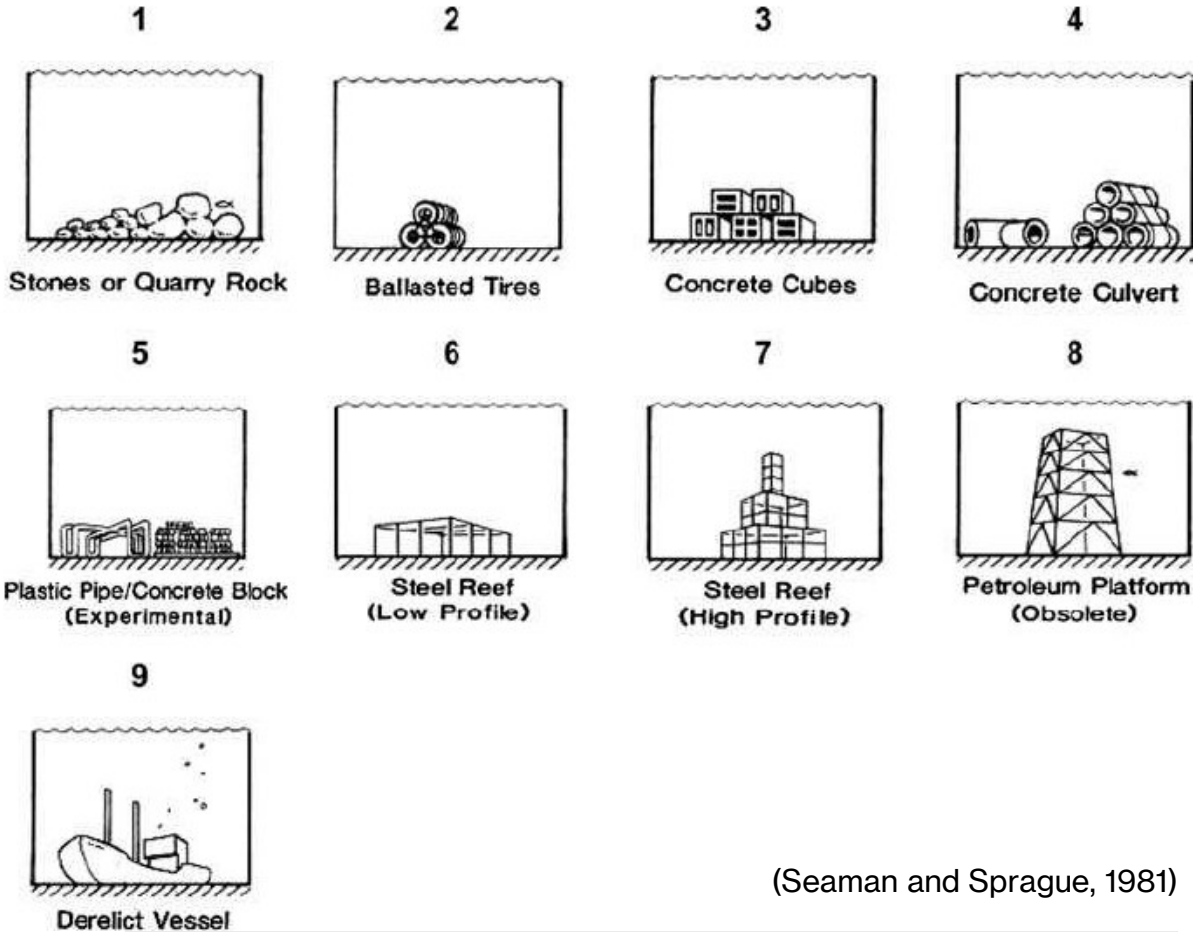
1st recorded marine ecological engineering tools, ~3,000 yrs. ago Mediterranean sea (Riggio et al., 2000)

1st national policy to enhance marine productivity, in Japan, Joo Emperor chronicles 1652-1655 (Thierry, 1988)

Material and purpose

Artificial reef characteristics
Dominant construction material (81.6%)
Ash
Brick
Ceramic
1 Concrete
Dead coral
Fibreglass
Mixed components
Other metal (e.g., aluminum)
Plastic
2 Rock (e.g., rubble, limestone)
Rubber (e.g., tires)
Shell
3 Steel
Wood

(Ramm et al., 2021)



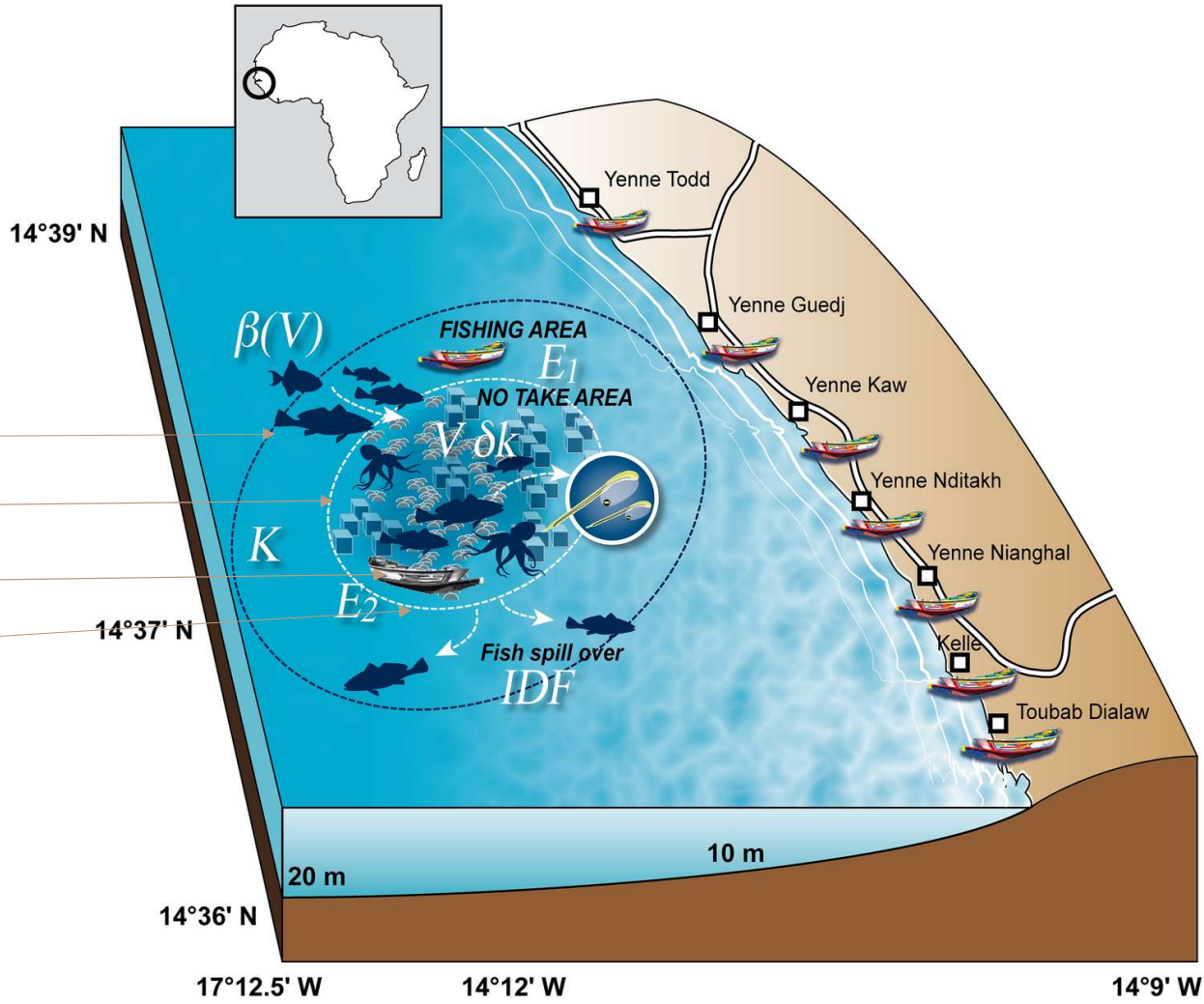
(Seaman and Sprague, 1981)

General goals

Not a “miracle” solution.

=> Need clear goal AND adapted management (upon goals)

- Production
- Protection
- Recreational
- Restoration



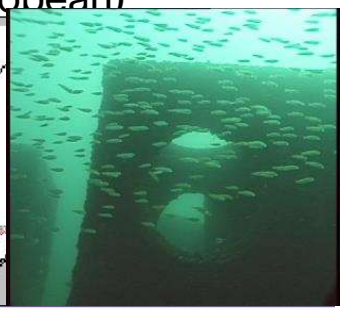
Brochier et al., 2021. Scientific reports

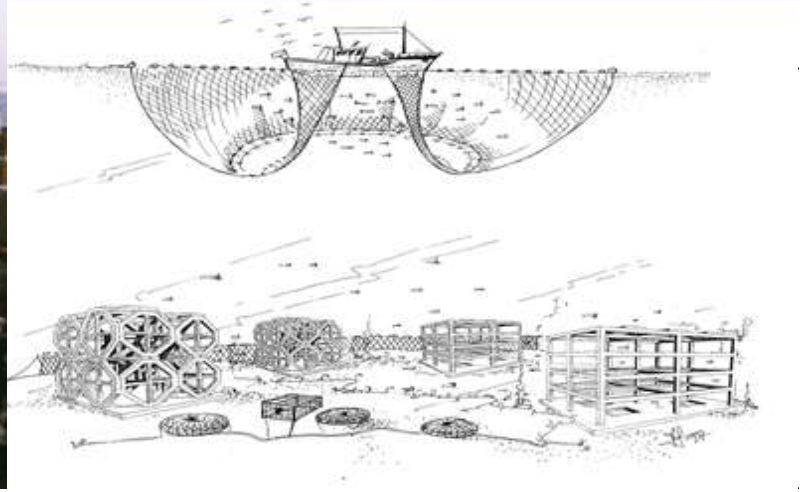
Portugal : fisheries productivity

In association with fishermen supported by scientists (IPIMAR) results after 23 years of follow-up

- CPUE x 2.2 (since 1990) and stable
- Increase divers from 15 to 20% (world class diving destination european)
- Lower operating costs
- re-stocking experiment (seabream)

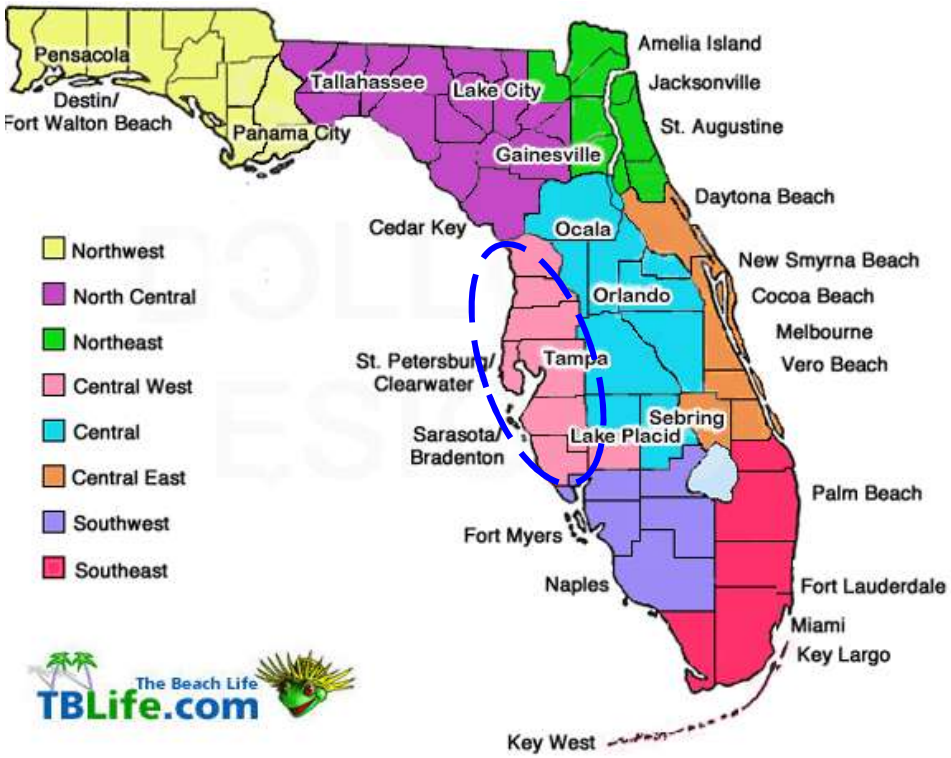
(Monteiro – Santos 1997 - 2007); Santos, MN, Monteiro, CC, & Leitão, F. (2011). The role of artificial reefs in the sustainability of Artisanal Fisheries. Artificial Reefs in Fisheries Management, 221-237





USA : recreationnal and touristical

- Florida: 2500 recreational sites, since 1970 (37 projects)
  Central West Counties : 1.3 million visitors (diving, fishing)



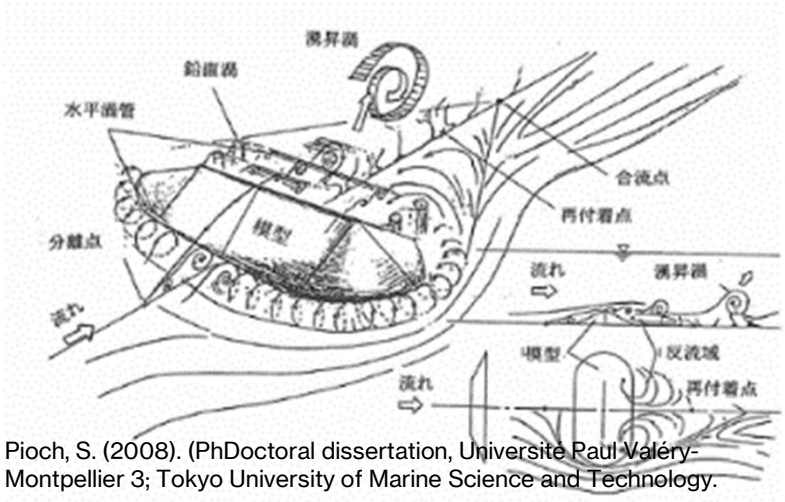
<u>Local economy:</u>
180 recreation sites
$ 200 million (€ 150 million)
2600 jobs
expense / day = 250 to $ 370 (€ 150-240)

K. Mille, Florida Fish and Wildlife Conservation Commission

Japan : marine-ranching (halieutic and restoration)

- 20,000 developed sites and 12% of the coastal area with AR,
- ~300 models of artificial reefs
- 650 million $ US invested (only public part.) in 2007
- National policy with fisheries and local communities

(Pioch., 2008)



Pioch, S. (2008). (PhDoctoral dissertation, Université Paul Valéry-Montpellier 3; Tokyo University of Marine Science and Technology.

Is it a good answer ? YES

Many publications to confirm that **WITHIN A GOOD MANAGEMENT** plan AR can be a good answer, see recent papers:

1. "**Artificial Reefs around the World: A Review of the State of the Art and a Meta-Analysis of Its Effectiveness for the Restoration of Marine Ecosystems"** Bracho-Villavicencio et al., 2023, Environments
2. "**Artificial reefs in the Anthropocene: a review of geographical and historical trends in their design, purpose, and monitoring**". Ramm et al., 2021, Bulletin of Marine Sciences
3. "**Marine artificial reefs, a meta-analysis of their design, objectives and effectiveness**". Vivier et al., 2021, Global Ecology and Trends

But… also failure due to mistakes in its use

- **Issue / controversy due mainly to mistakes and misuses :**

1. “Recycled” material used as AR : Florida Osborne tires AR, wreck used as RA and **PCB pollution/oil spill** (Martore et al., 1995)
2. **Invasive species supported** by smooth (concrete/steel/plastic surfaces) construction material (see Gauff et al., 2023);
3. **Modified hydrodynamic impact burial/current**;
4. **Aesthetic degradation** of underwater landscapes (Pioch, 2008).
5. **Ecological trap** design enhance fish mortality (see Komyakova, et al. (2021). A multi-species assessment of artificial reefs as ecological traps. *Ecological Engineering)*
6. **Decommissioned platform/wrecks** and controversies over attraction/production (top/big predator only enhance catchability, NNIS) (Bombace, 1989)

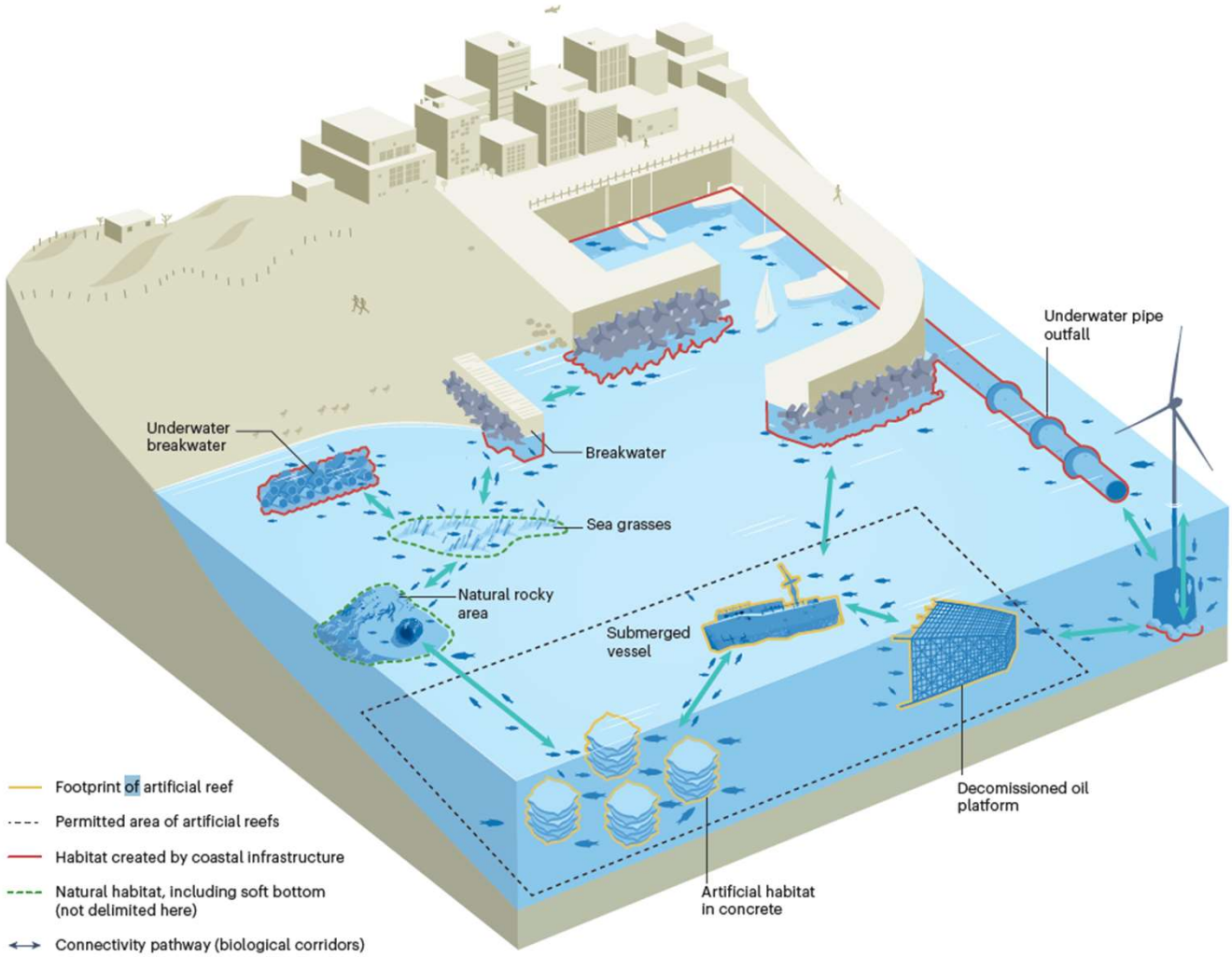
Osborne « tire » AR

Unsightly landscape integration

New field of research: spatial connectivity

Connectivity pathways between natural reef and artificial constructions (infrastructure or AR)

=> **need for ecological considerations before the immersion** of any human construction, because they will **always be colonized** for better or less

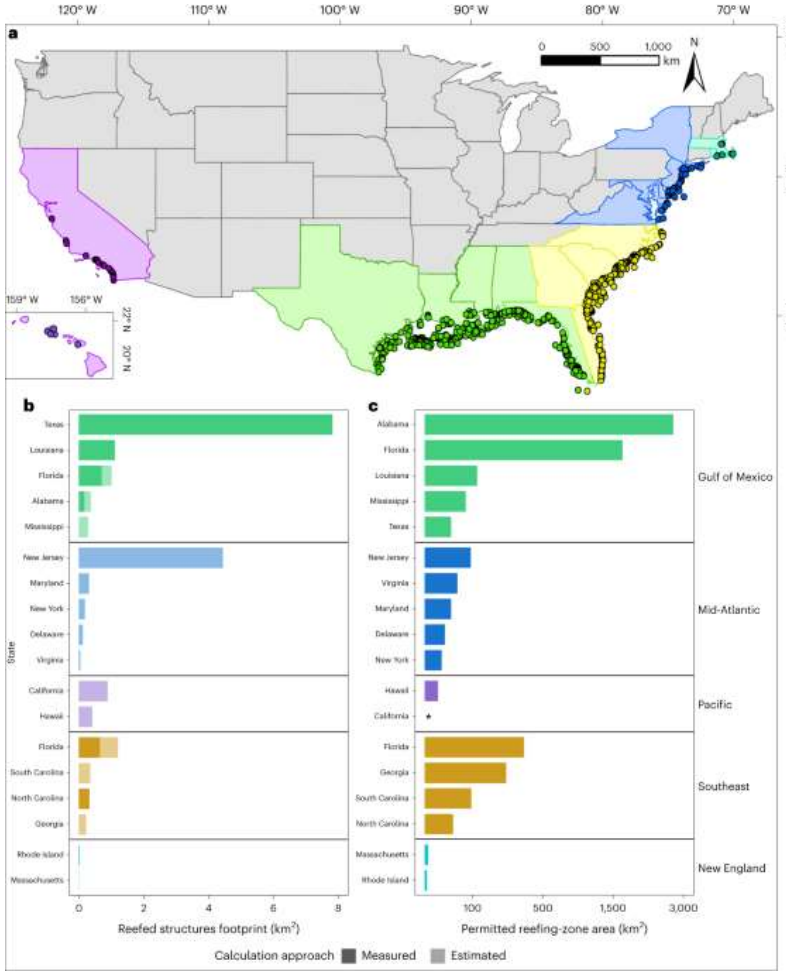


Pioch, S., Patterson III, W. F. (2024). Mapped US artificial reef footprint. *Nature Sustainability*, *7*(2), 100-101.

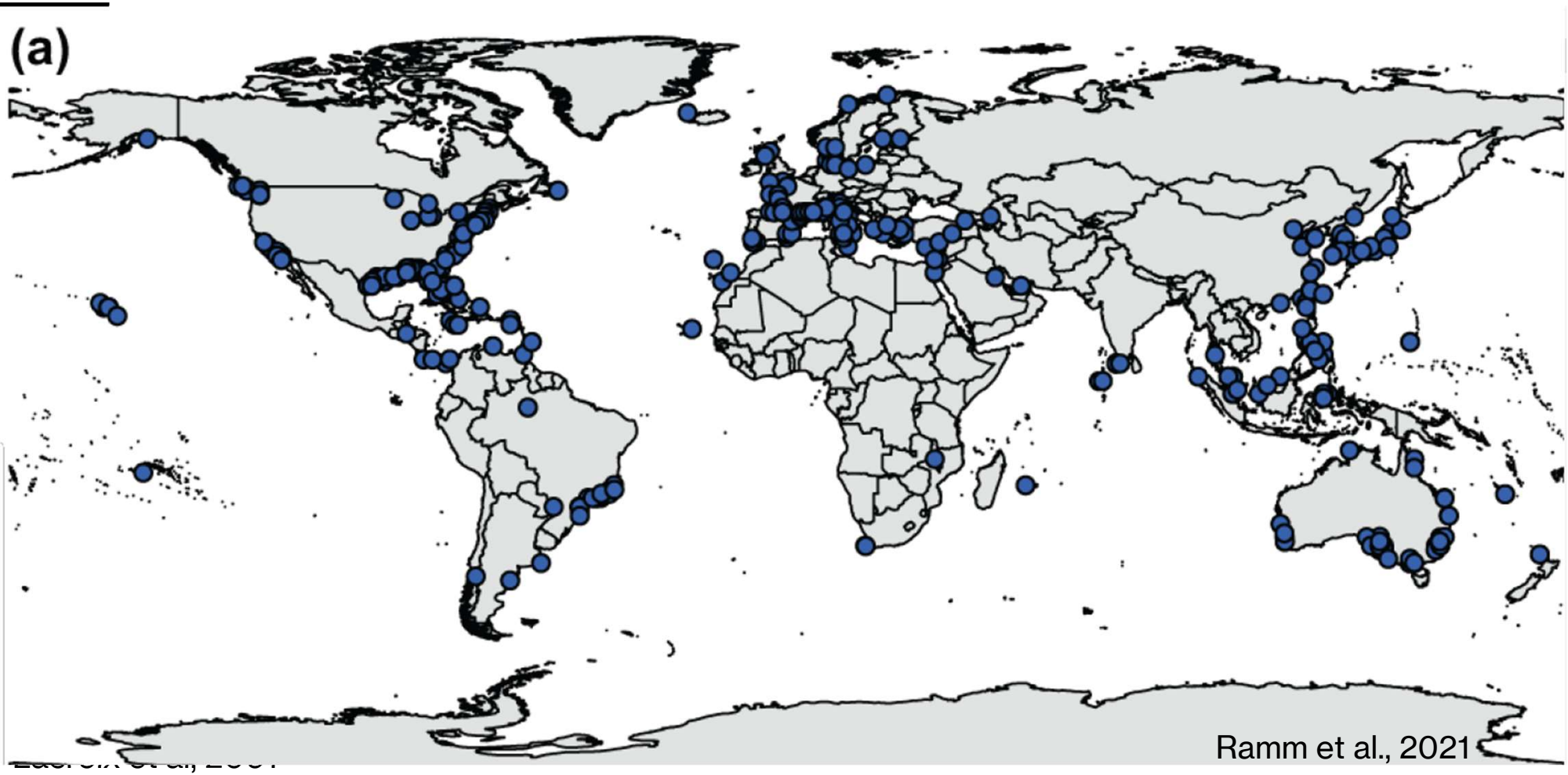
Artificial reef footprint in the United States ocean (Paxton et al., 2024, Nature sust.)

- **original classification for the wide variety of structures** deployed
- **permitted AR zones** on the seafloor are about **5 811,33 km²**,
- **cumulative footprint** of deployed reefs is only approximately **19,23 km²,** nearly **<u>300 times less</u>**.
- **in 2020, 99.67% of the permitted zoned remained available** for AR deployment
- in the south-eastern U.S., the AR footprint represents **< 0.01% of that of natural reefs and only covers 2.57% of the continental shelf** (-10 to -200 m depth)

=> they have developed and effective approach for estimating AR aerial coverage

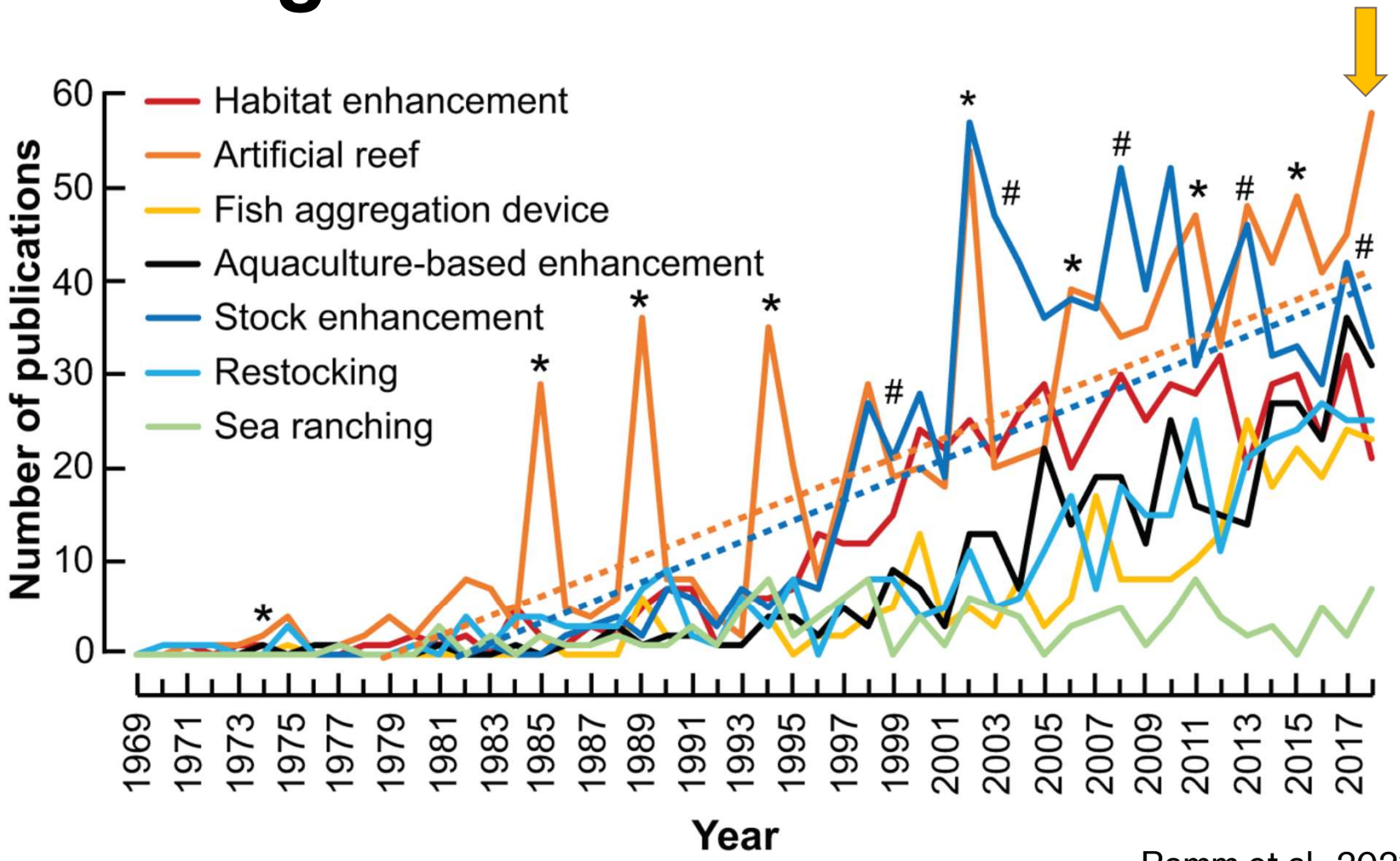


Today, world map of AR publications (WOS)



Ramm et al., 2021

Growing research interest



Ramm et al., 2021

Important interest since 3 yrs

UNITED NATIONS DECADE ON
ECOSYSTEM
RESTORATION
2021-2030