RÉPUBLIQUE FRANÇAISE
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Ifremer

La vision par ordinateur au service de l'étude des écosystèmes marins profonds

beep
UMR 6197
Biologie et Écologie des Écosystèmes marins Profonds

Catherine BORREMANS
Laboratoire Environnement Profond

ORASIS 2025
10 Juin, Le Croisic

Plan de la présentation

Les écosystèmes marins profonds

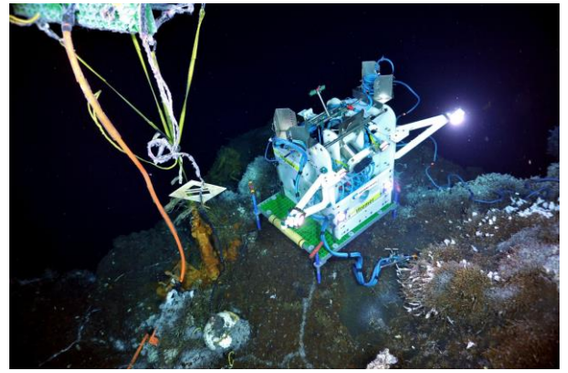
Etude par imagerie

Méthodes d’analyse d’images

Vers des approches automatisées

Contextes national et international

Enjeux de standardisation et de partage

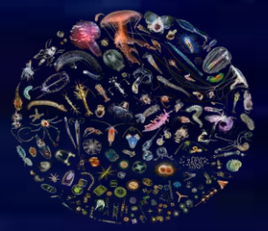


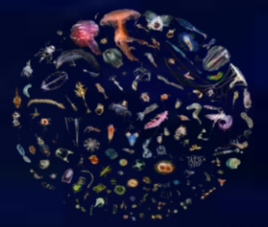
01.

Les écosystèmes marins profonds

Etude par imagerie

L’océan profond





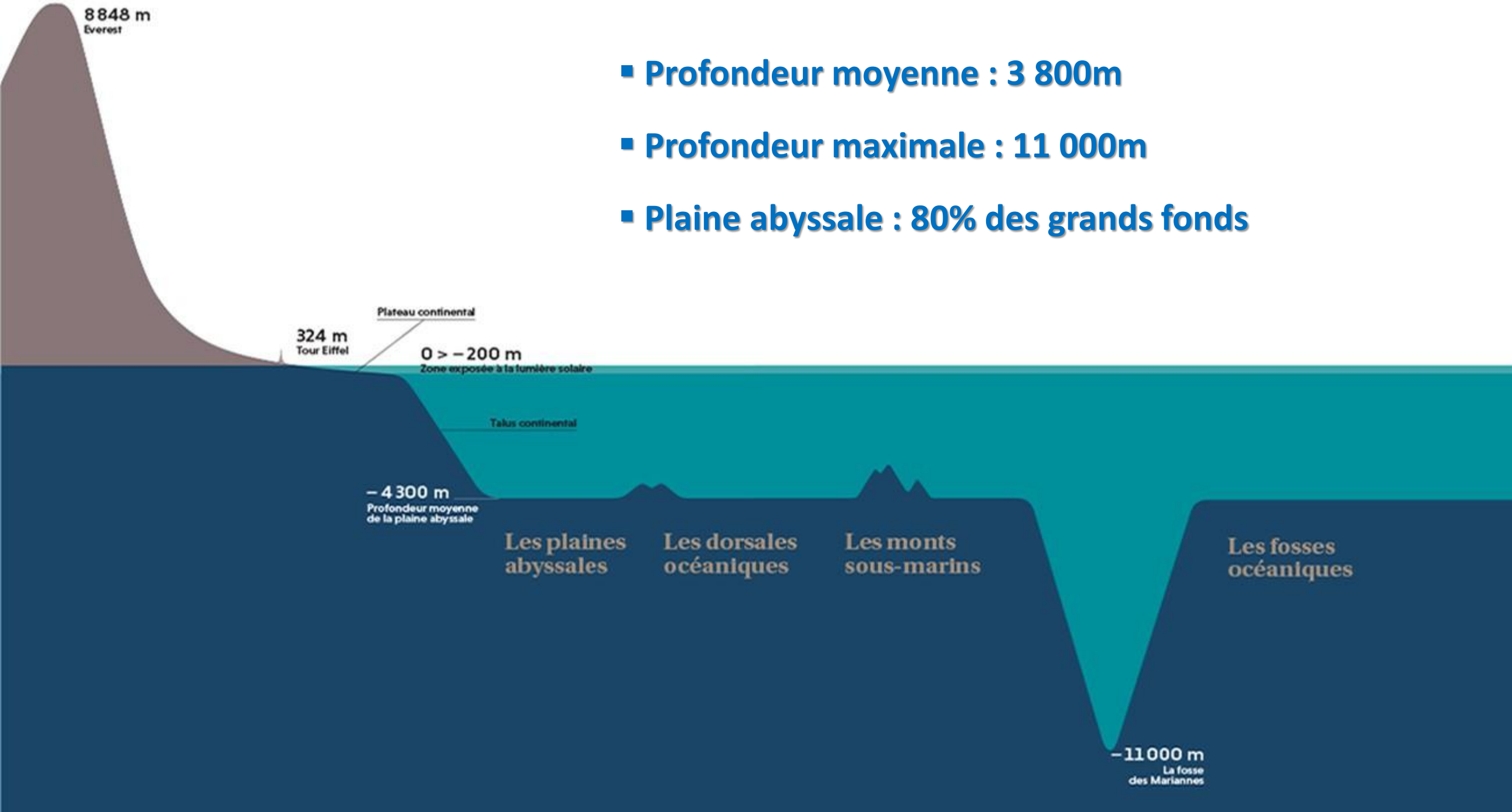
Zone aphotique
Pas de lumière = pas d’algue

La nourriture provient surtout des déchets de la production primaire de surface

Il fait froid

La pression augmente de 1 bar tous les 10 m

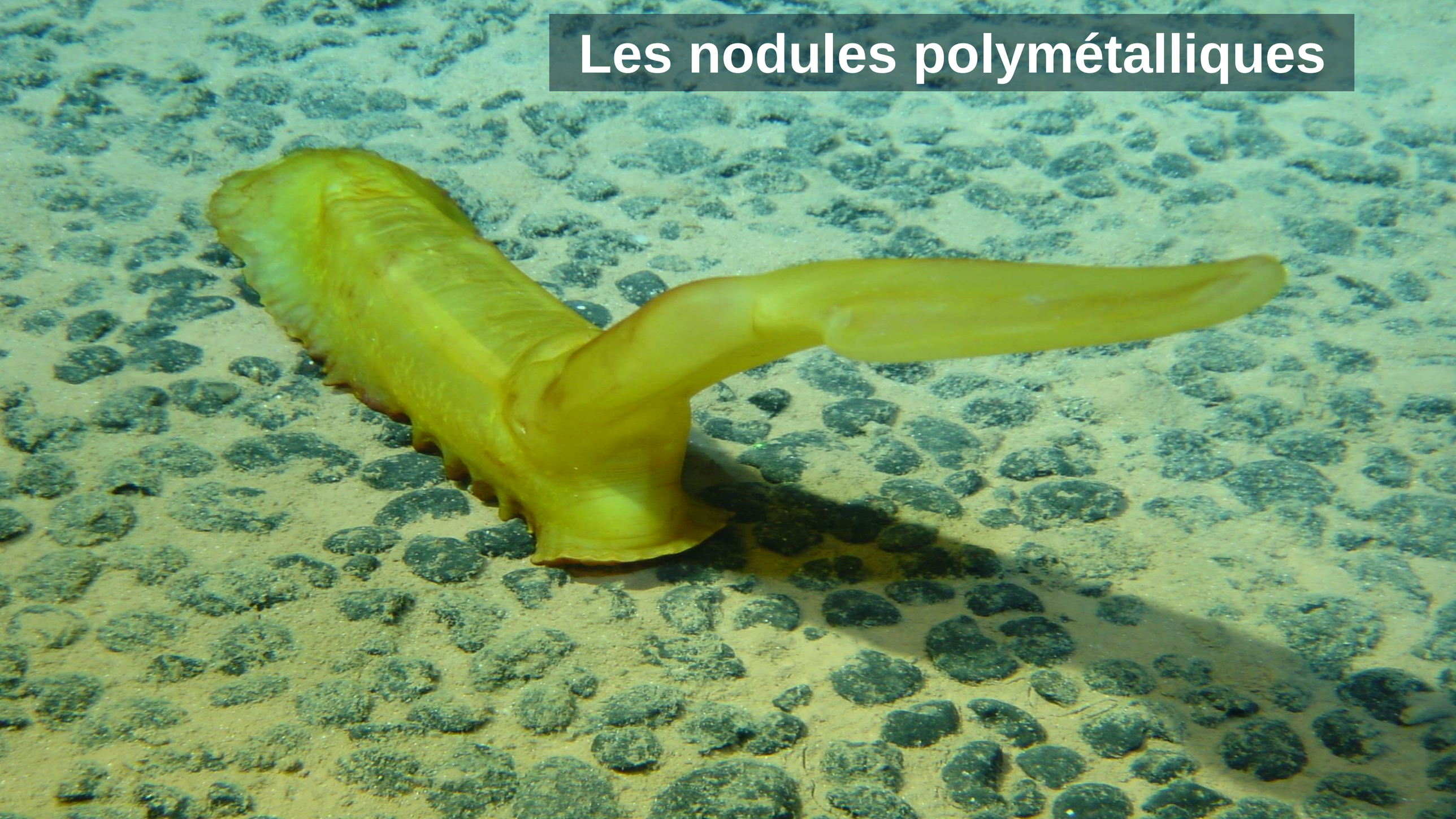
- **Profondeur moyenne : 3 800m**
- **Profondeur maximale : 11 000m**
- **Plaine abyssale : 80% des grands fonds**



Les plaines abyssales

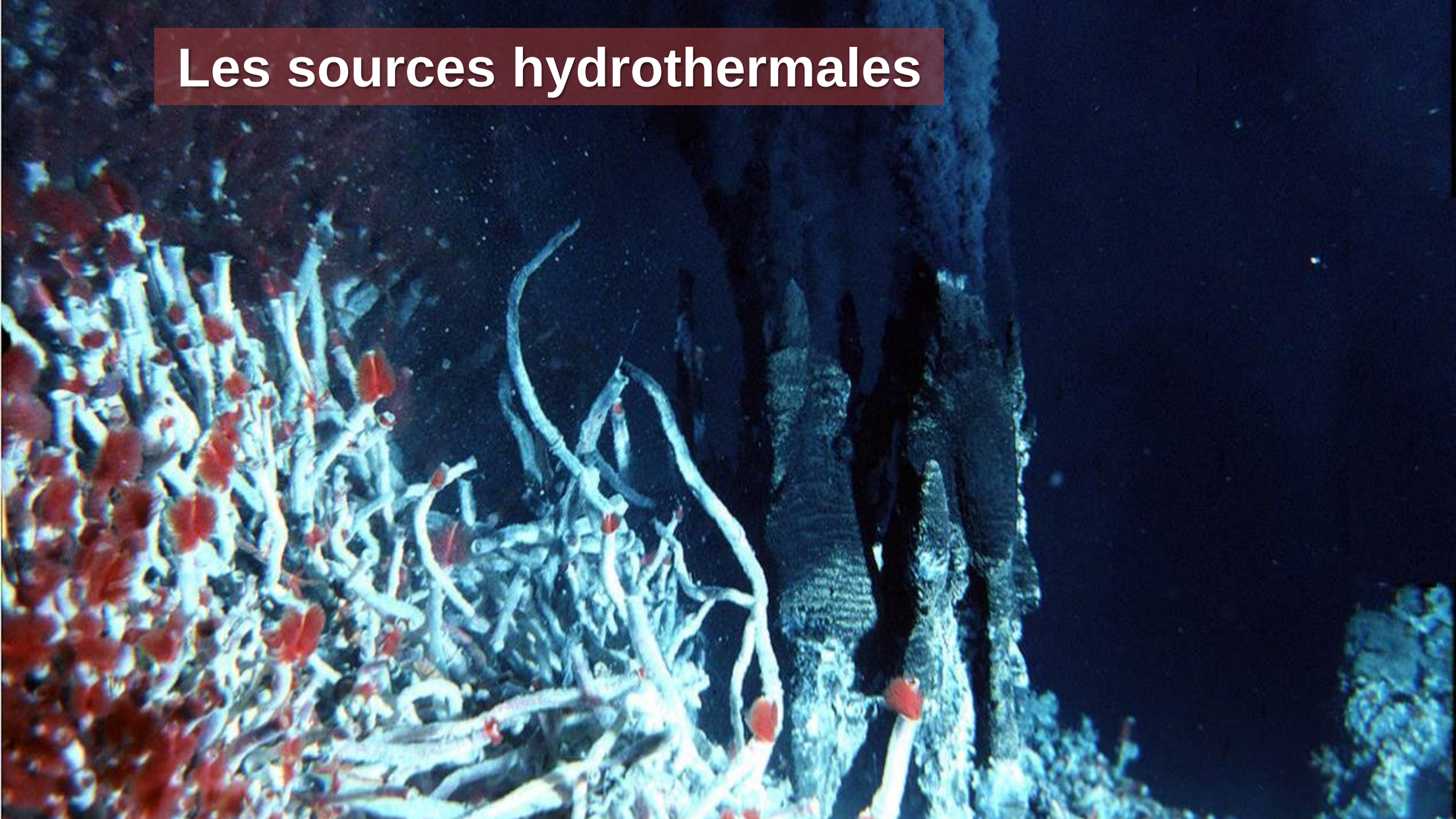
CSSF-ROPOS/NEPTUNE

Les nodules polymétalliques



Les coraux profonds, les monts sous-marins, les canyons

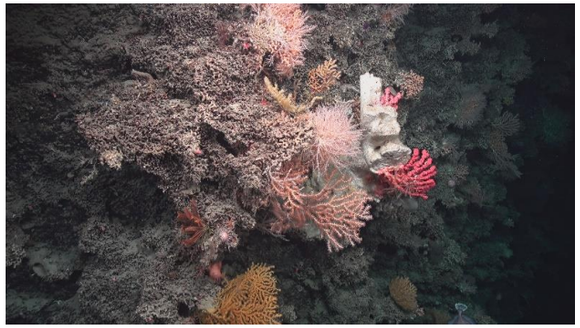
Les sources hydrothermales



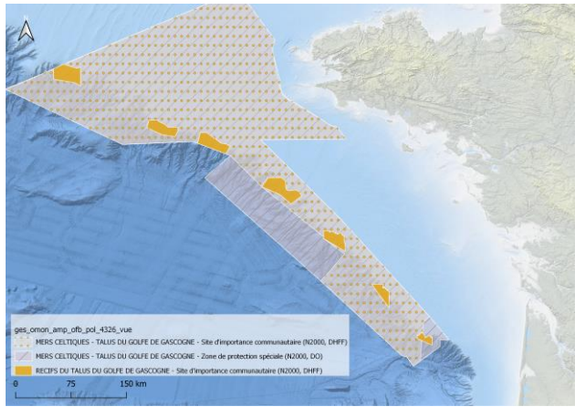
Les sources froides

Pourquoi étudier les écosystèmes profonds ?

- Dernière frontière de notre planète
  - Grande diversité d'espèces avec plus d'un million non découvertes à ce jour
  - Adaptations à des environnements extrêmes et variables
  - Rôle dans le fonctionnement global de l'Océan
  - Sécurité (câbles sous-marins et défense)



- Des ressources convoitées
  - Des contraintes à évaluer / quantifier
  - Une Réglementation internationale en construction



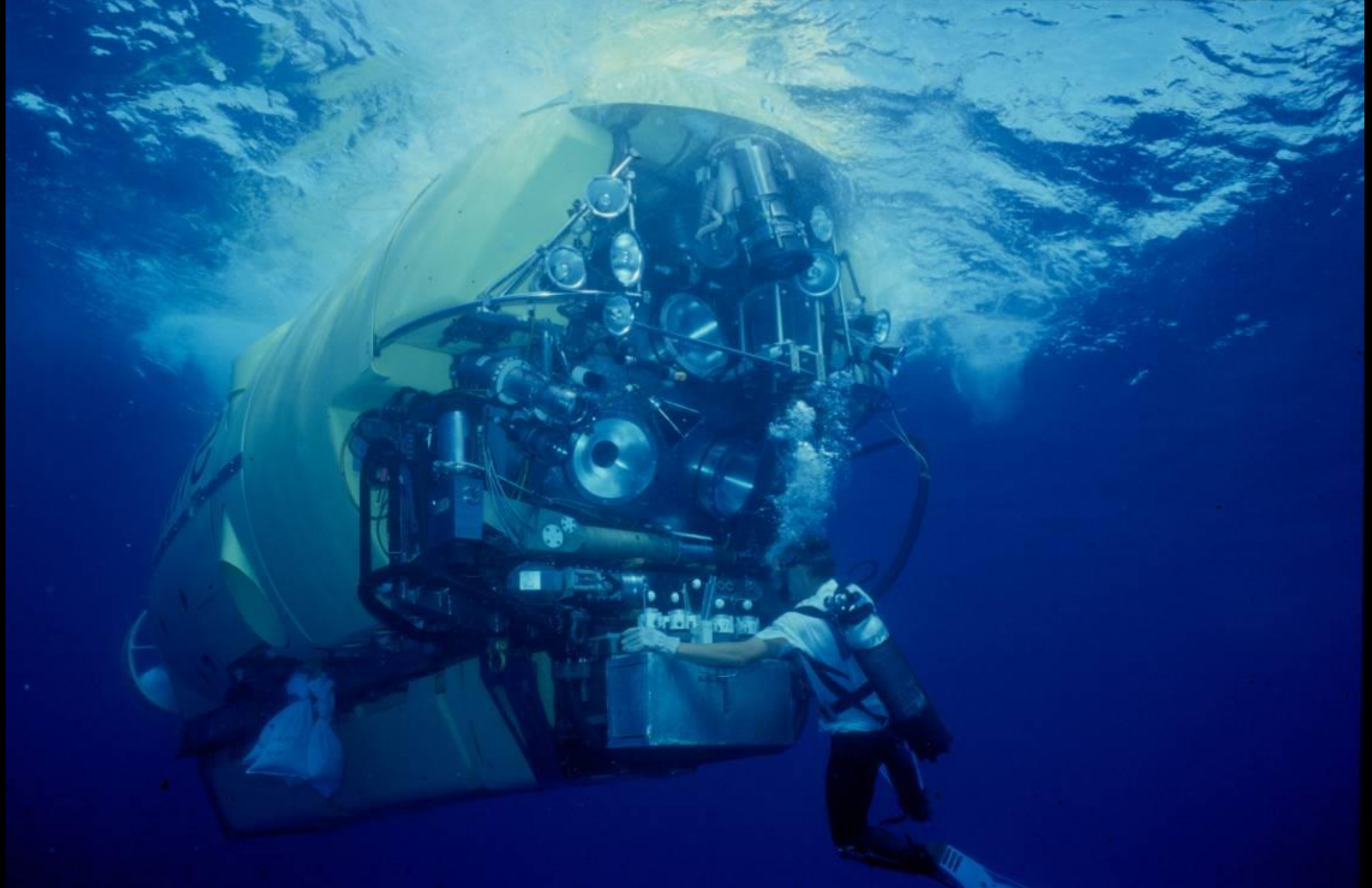
- Demande sociétale de préservation de la diversité biologique : patrimoine commun de l'Humanité

Comment étudier les écosystèmes profonds ?

Un laboratoire embarqué

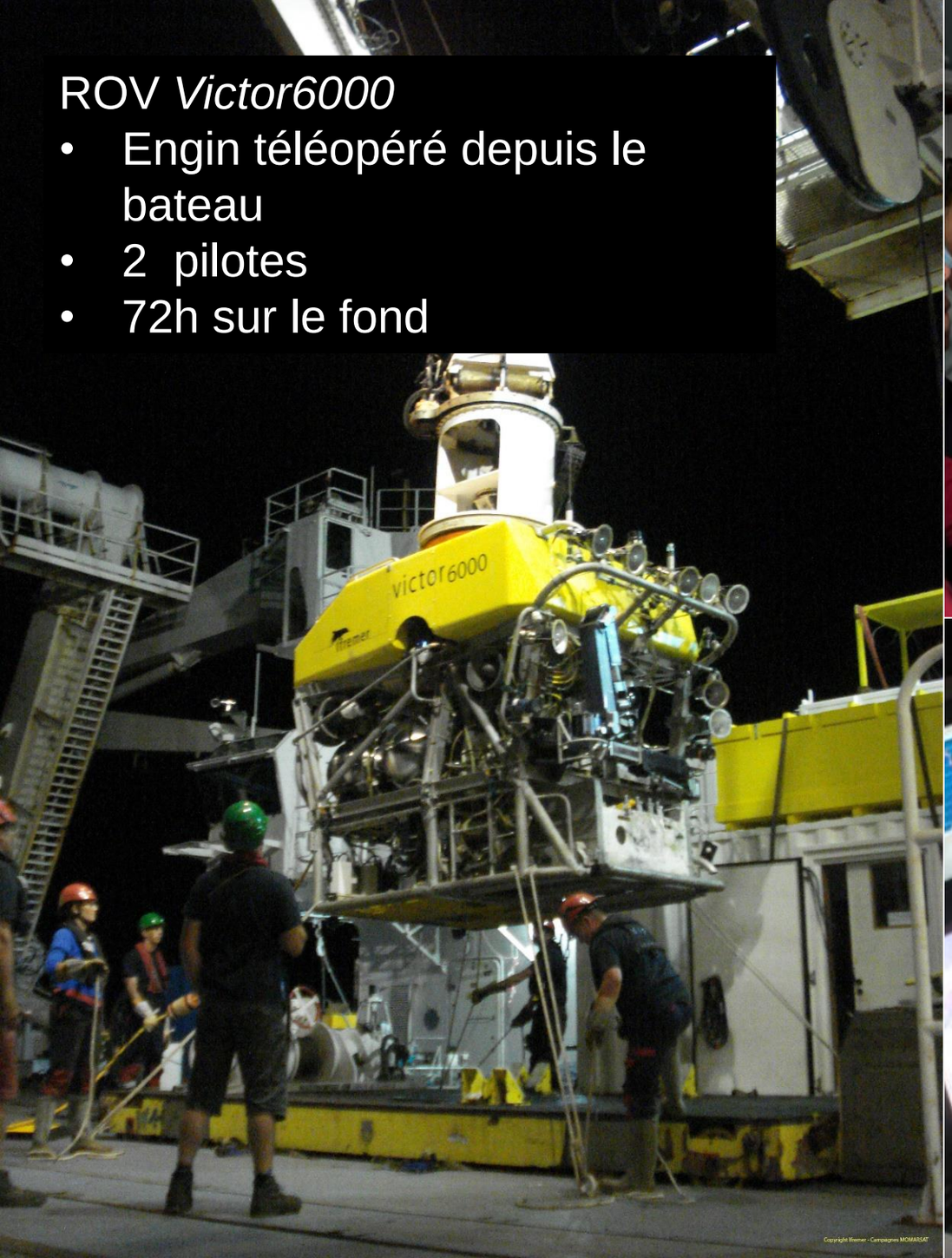
- 107 m de long x 20 m de large
- 35 membres d'équipage
- 40 scientifiques embarqués
- 250 m^2 de laboratoire

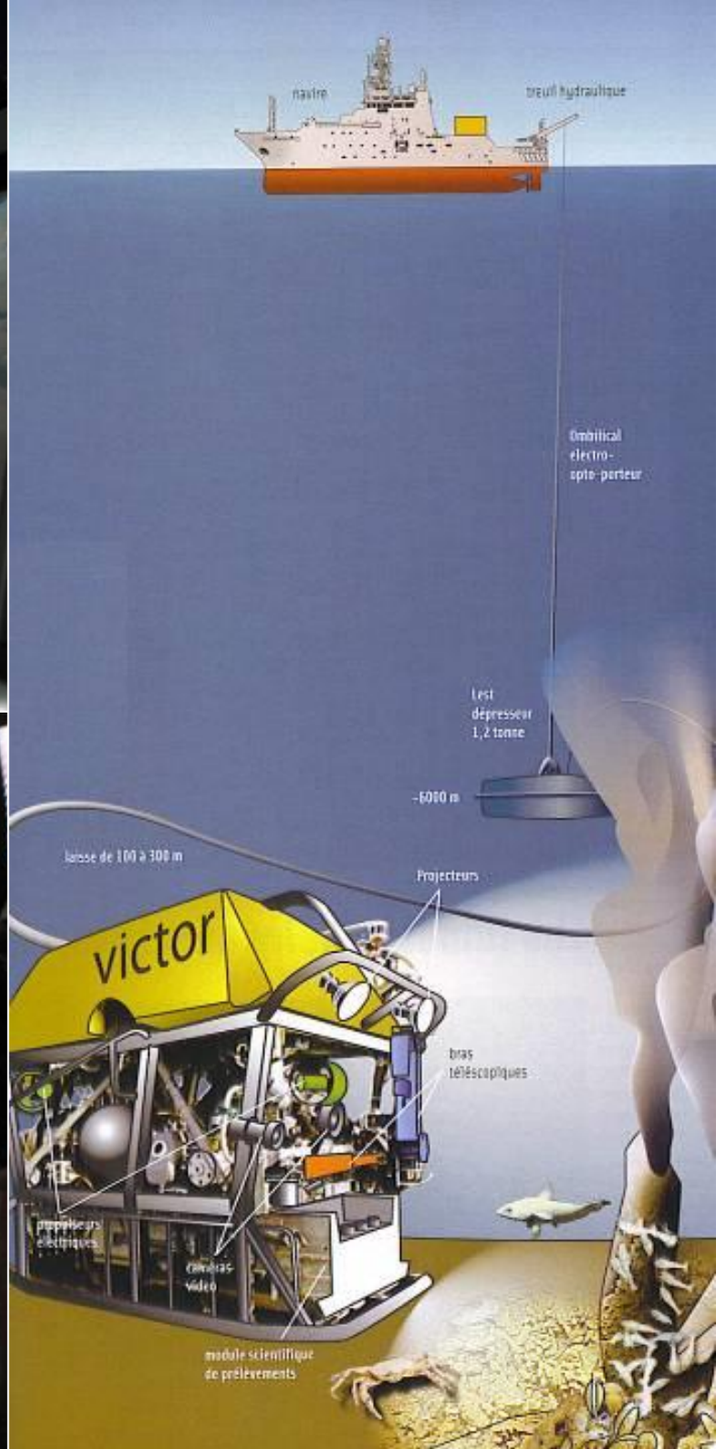
FLOTTE OCÉANOGRAPHIQUE FRANÇAISE par l'Ifremer



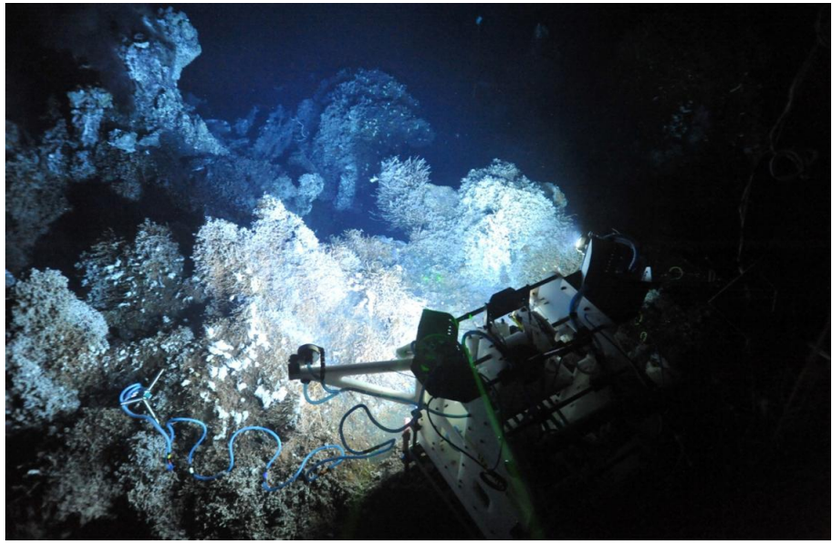
ROV *Victor6000*

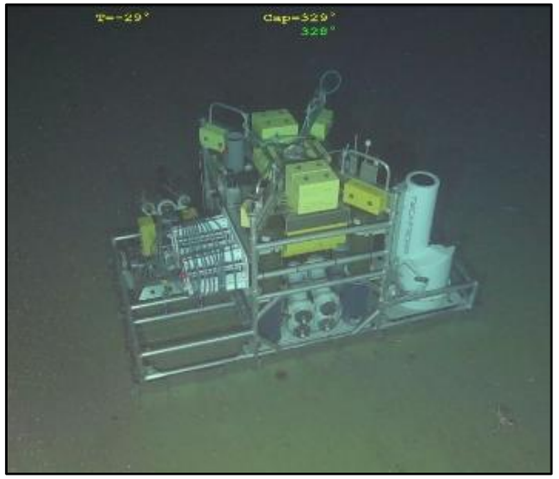
- Engin téléopéré depuis le bateau
- 2 pilotes
- 72h sur le fond

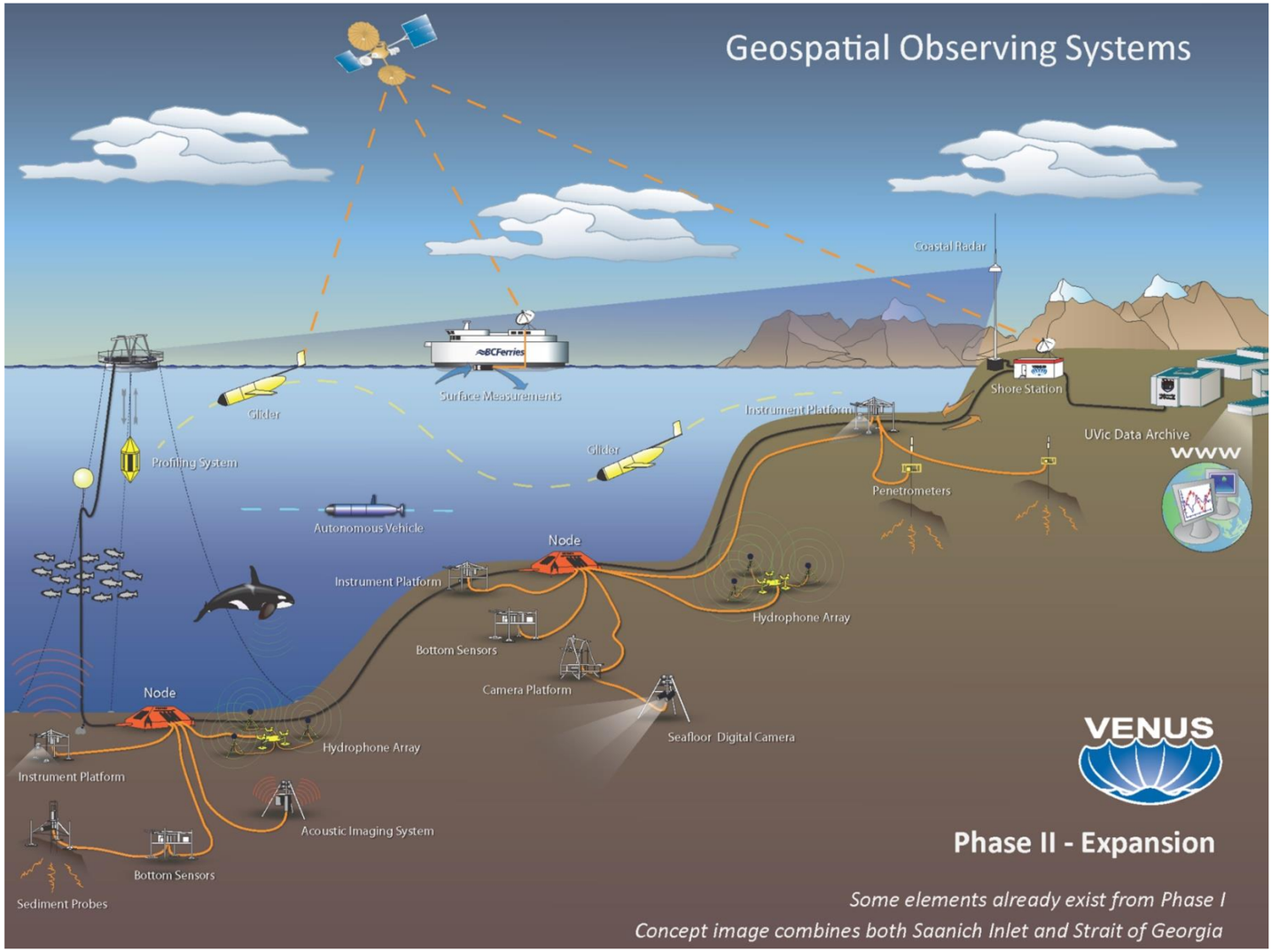




L’accès à la dynamique temporelle : Les observatoires fond de mer

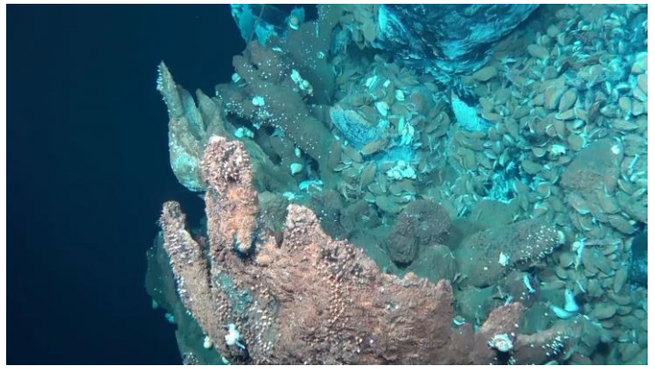






L’imagerie pour étudier les habitats et la macrofaune benthiques

Avec les progrès de la technologie sous-marine, l'acquisition d'images est devenue un outil inestimable pour collecter des informations sur l'habitat et la distribution de la faune, ainsi que sur l'abondance et la taille des espèces, mais aussi sur le comportement, les habitudes alimentaires, la croissance, la reproduction ainsi que la réponse de l'organisme aux changements de l'environnement.



L'imagerie, et en particulier l'imagerie optique, fournit une multitude de données écologiques qui peuvent être partagées et comprises par la société

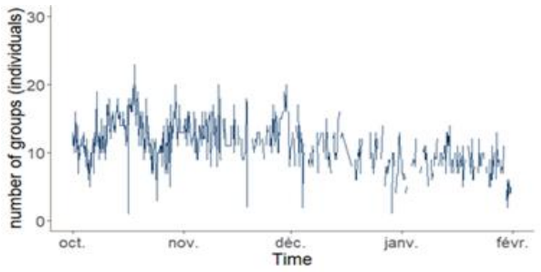
L’imagerie pour étudier les habitats et la macrofaune benthiques

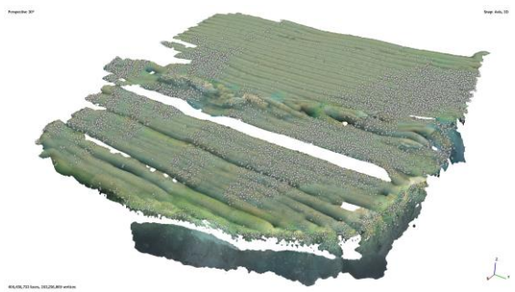
L’imagerie: un outil indispensable pour l’étude des écosystèmes benthiques

- Fast acquisition / Large study area
  → Large temporal and spatial scales
- Continuous
- Many information
  -> geological, faunal, anthropic…
- Nonintrusive and non-destructive
- Access to difficult to study ecosystems

Wide progress:

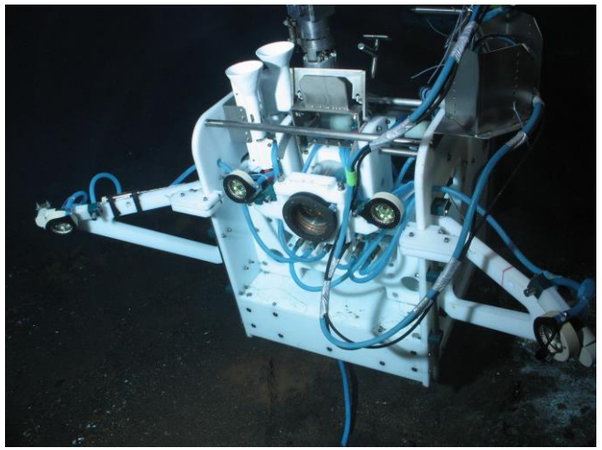
- Photogrammetry: high resolution 3D models
- Deep-learning: automatic feature recognition
- Collaborative online tools: Biigle, Deep Sea Spy…

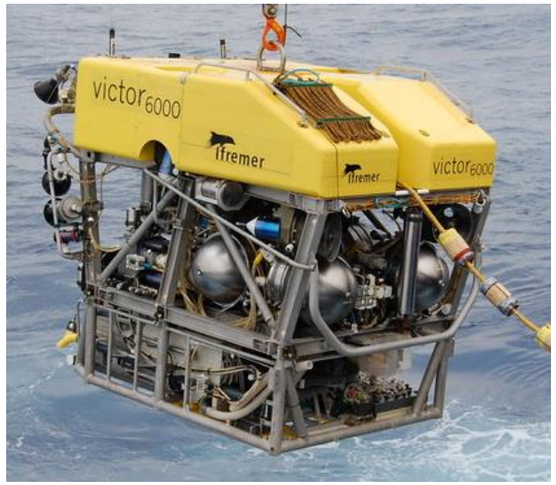


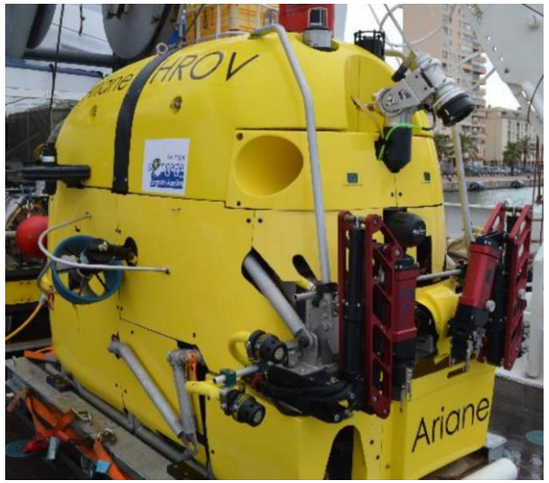


Acquisitions

Sous-marins / Observatoires / …







Camera

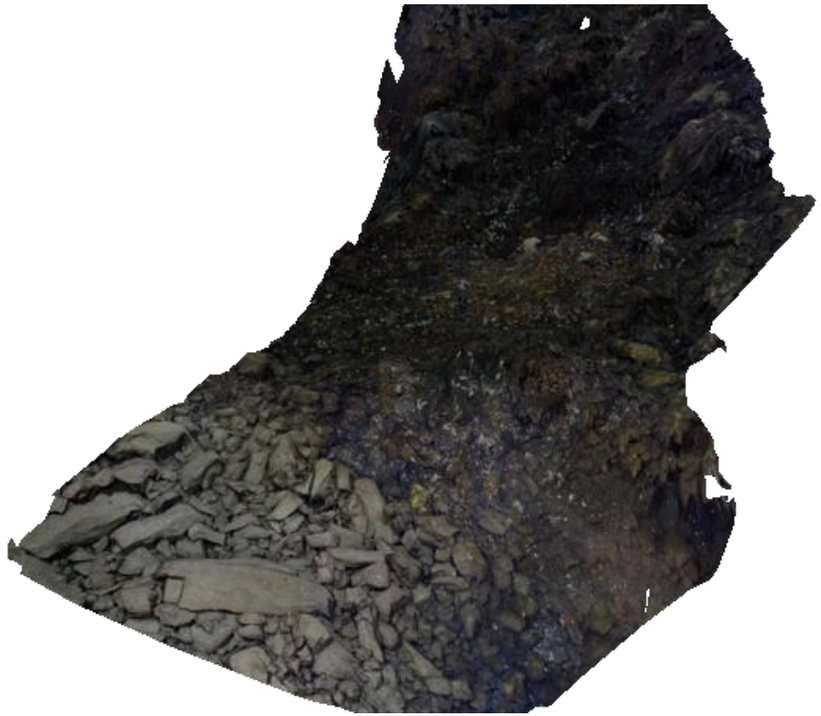
- Photos
- Vidéos

Navigation

- Position
- Attitude

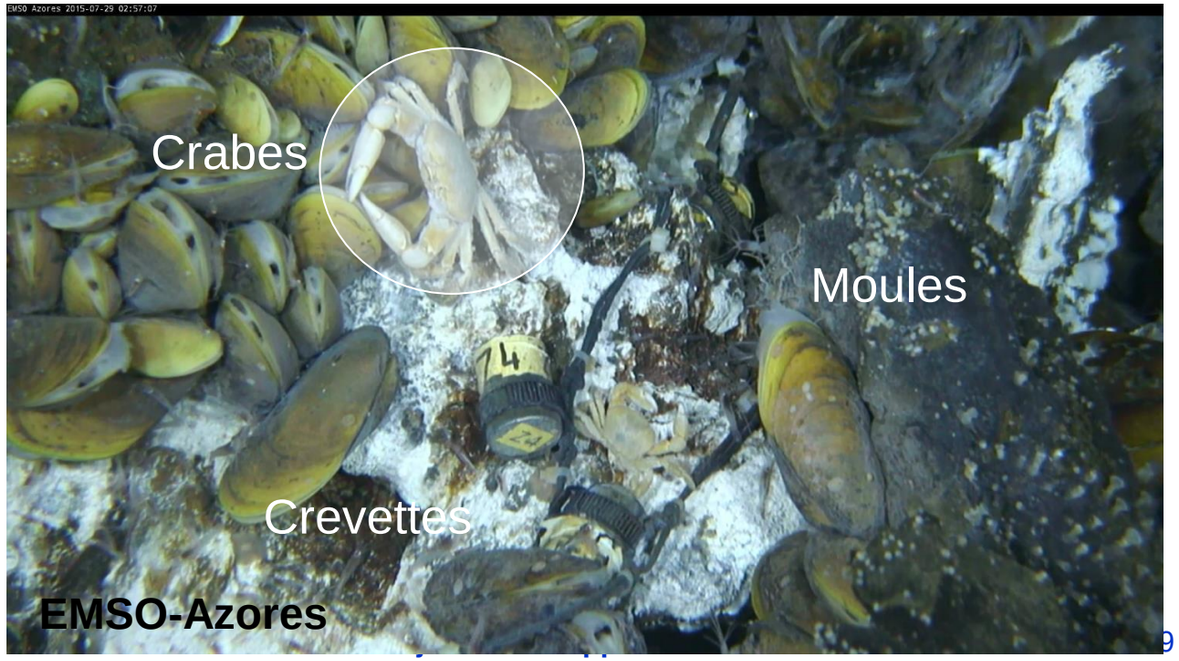
Traitement

Reconstruction 3D : photogrammétrie



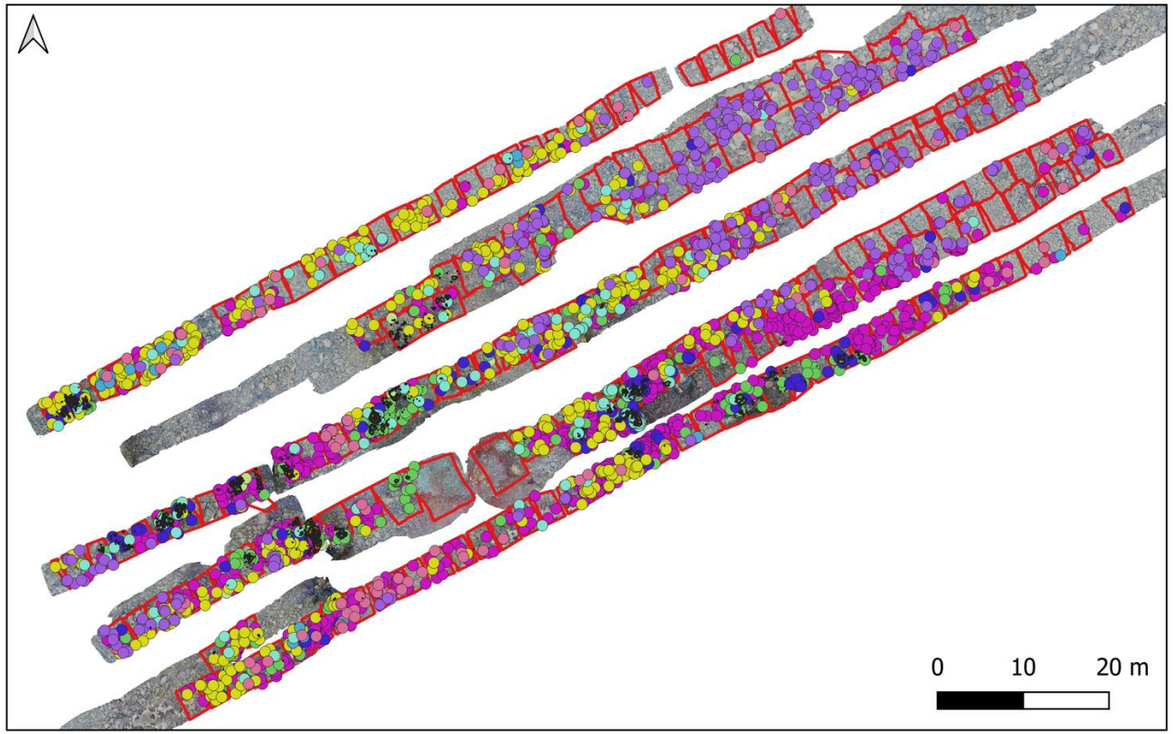
& mosaïques 2D / orthomosaïques

Annotation de la faune



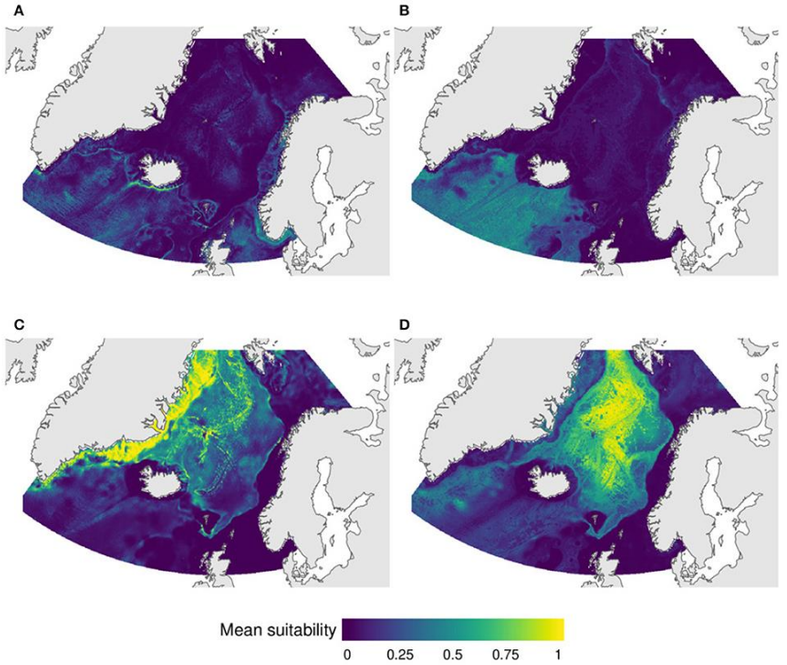
Analyses

Cartes de distributions



Individus
- Actiniaria
- Alcyonacea
- Amphipoda
- Brachyura
- Caridea
- Crinozoa
- Eosipho
- Galatheoidea
- Lithodoidea
- Osteichthyes
- Phymorhynchus
- Polynoidae
- Porifera
- Emprises des images

Modèles prédictifs

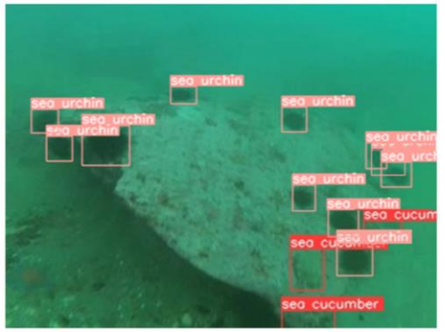


Travaux de Marin Marcillat

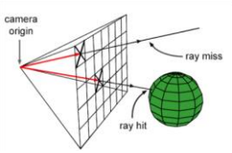
Enjeux et problématiques

Volume colossal de données acquises (BIG DATA) qui nécessite des approches automatiques pour traiter les images acquises

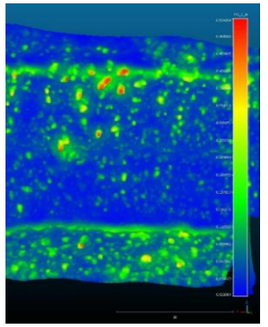
- Avènement de l'intelligence artificielle (IA) a permis le développement d'algorithmes facilitant le traitement automatique de grands jeux de données
- Nécessité d'une phase d'apprentissage très chronophage !



Exploitation des modèles 3D



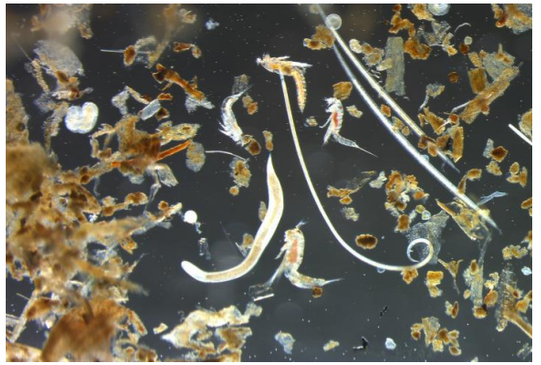
- Reprojection des annotations sur les modèles 3D



- Géomorpho-métriques à partir des modèles 3D
  - Pente, rugosité..

L’imagerie pour étudier la méiofaune

La méiofaune marine est un groupe d’animaux assez petits (20µm à 1mm) vivant dans le compartiment benthique, c'est-à-dire dans le sédiment sur le fond marin.



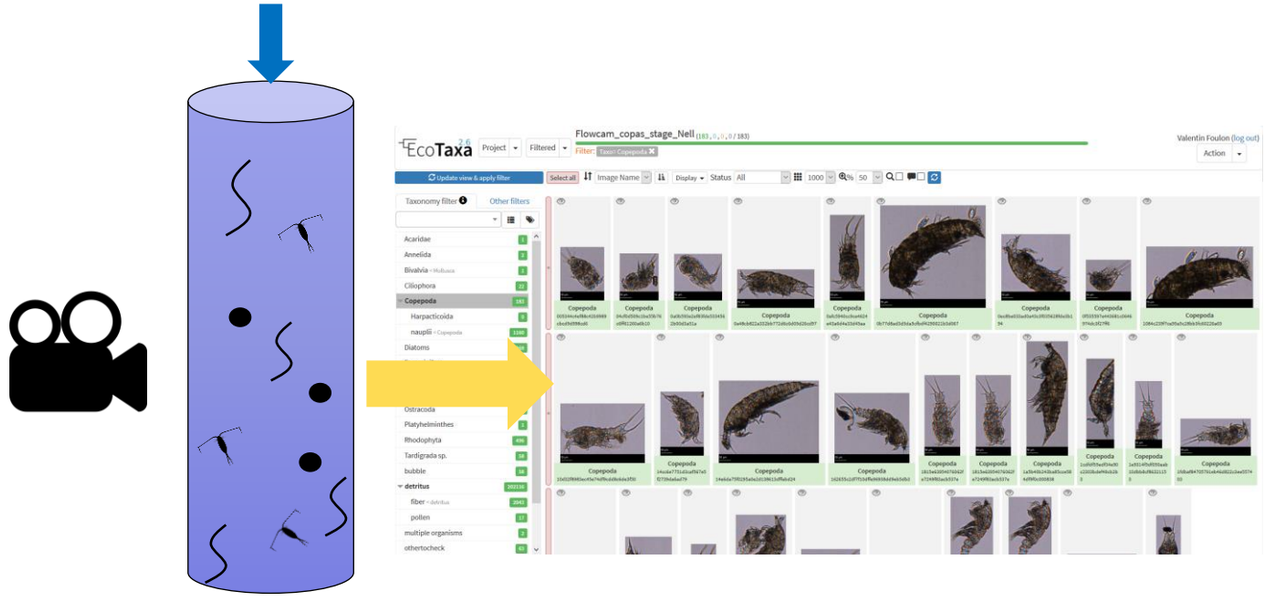
La méiofaune benthique est un indicateur crucial pour l'évaluation de l’impact anthropique sur les écosystèmes marins :

- Réaction rapide aux impacts
- Réaction à de faibles concentrations de contaminants
- Présente dans tous les sediments, du milieu côtier au milieu profond

Enjeux et méthodes innovantes

Besoin d'automatisation et de méthodes efficaces et rapides pour l'identification massive des organismes de la méiofaune :

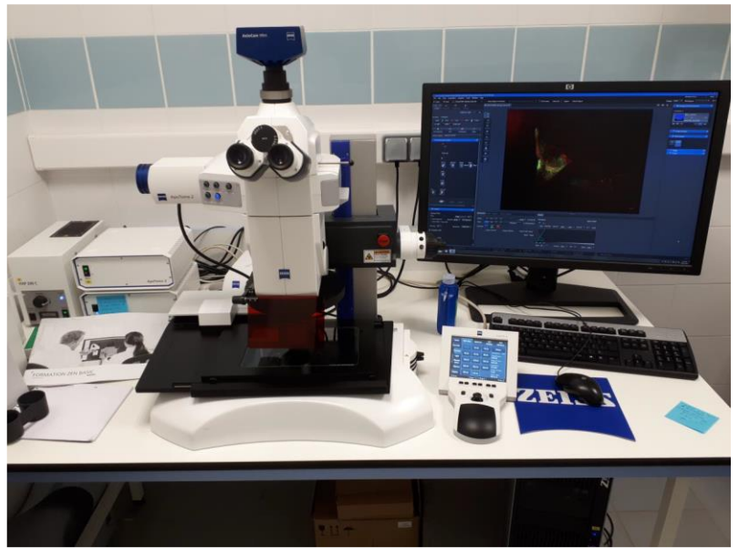
- outil d'imagerie et d'identification automatique de la méiofaune
- développement et entraînement de réseaux de neurones (IA) pour optimiser la reconnaissance automatisée



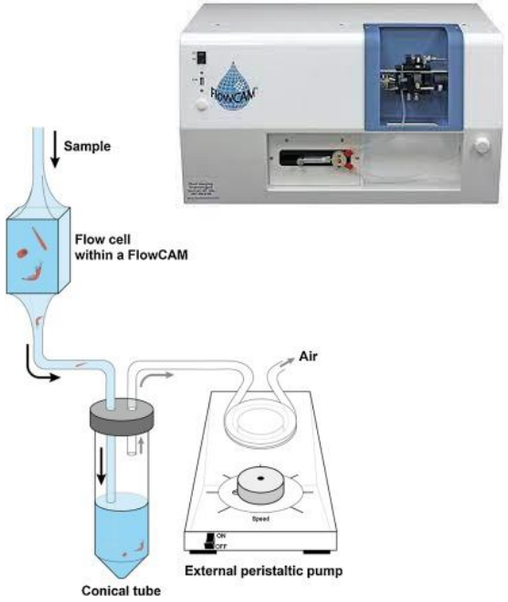
La microscopie et l’imagerie en flux

Testing and assessing resolution, throughput, data volume and quantitative power of:

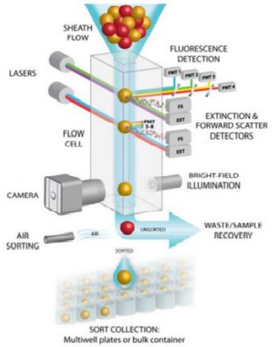
- HR microscopy 2D, 3D
- LR flow imaging (ZooCAM, FlowCAM, LISST-Holo2)
- LR flow imaging + automatic sorting (COPAS)



Axio Zoom (ZEISS)



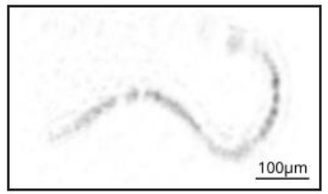
FlowCAM

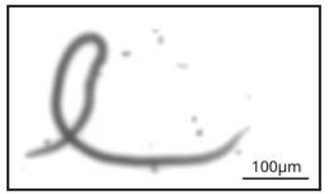


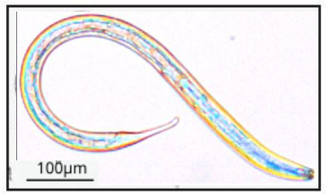
- Flow cytometer for large particles (20µm – 800µm) : **Mesure / Sorting / Image**
- Working with delicate samples (pump by low pressure)
- Working with water, PBS, FSW,…
- Staining with Phloxine B as discriminant marker for meiofauna

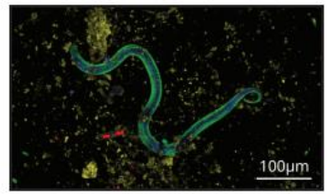
COPAS Vision

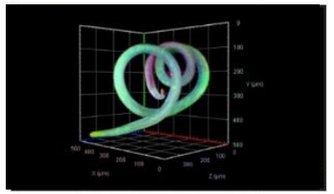
La microscopie et l'imagerie en flux







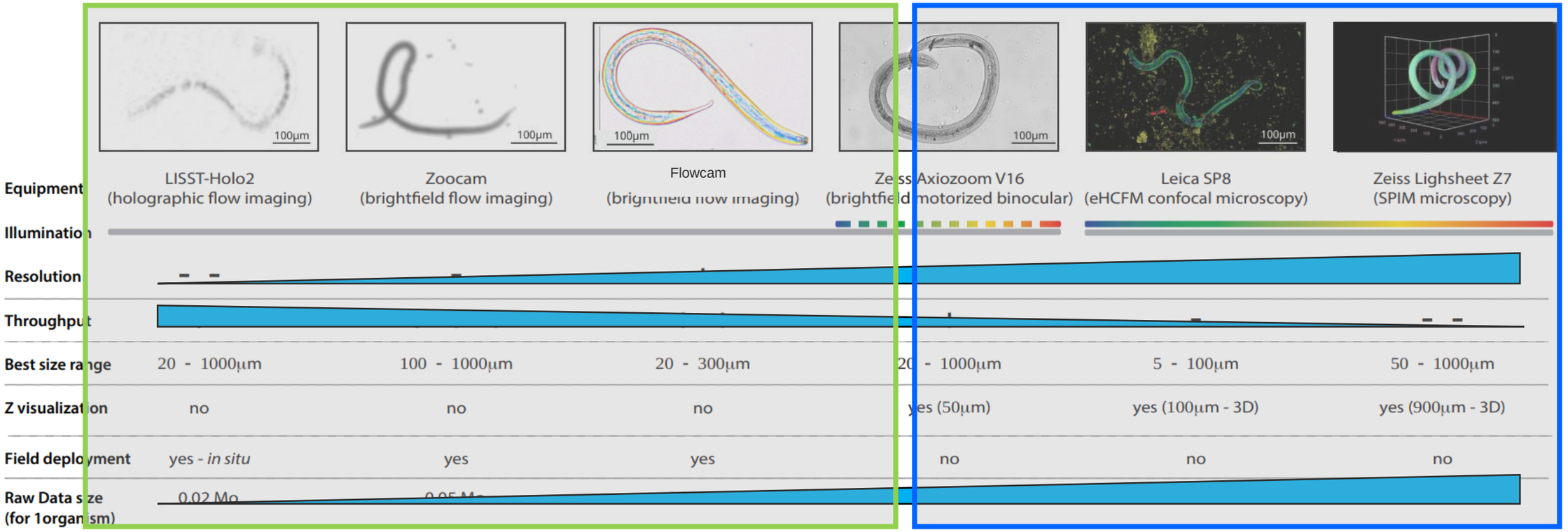




	LISST-Holo2 (holographic flow imaging)	Zoocam (brightfield flow imaging)	Flowcam (brightfield flow imaging)	Zeiss Axiozoom V16 (brightfield motorized binocular)	Leica SP8 (eHCFM confocal microscopy)	Zeiss Lighsheet Z7 (SPIM microscopy)
Equipment						
Illumination						
Resolution	- -	-	+	+ +	+ + +	+ + +
Throughput	?	+ + +	+ +	+	-	- -
Best size range	20 - 1000µm	100 - 1000µm	20 - 300µm	20 - 1000µm	5 - 100µm	50 - 1000µm
Z visualization	no	no	no	yes (50µm)	yes (100µm - 3D)	yes (900µm - 3D)
Field deployment	yes - *in situ*	yes	yes	no	no	no
Raw Data size (for 1organism)	0.02 Mo	0.05 Mo	0.002 Mo	800 Mo	100 Mo	7000 Mo

From: *Foulon, V., Benzinou, A., Nasreddine, K., Qayyum, A., Daché, E., Foulquier, V., Borremans, C., Malloci, M., De Vargas, C. and Zeppilli, D. (2025), Meiofauna investigation and taxonomic identification through imaging—a game of compromise. Limnol Oceanogr Methods.* https://doi.org/10.1002/lom3.10690

La microscopie et l'imagerie en flux



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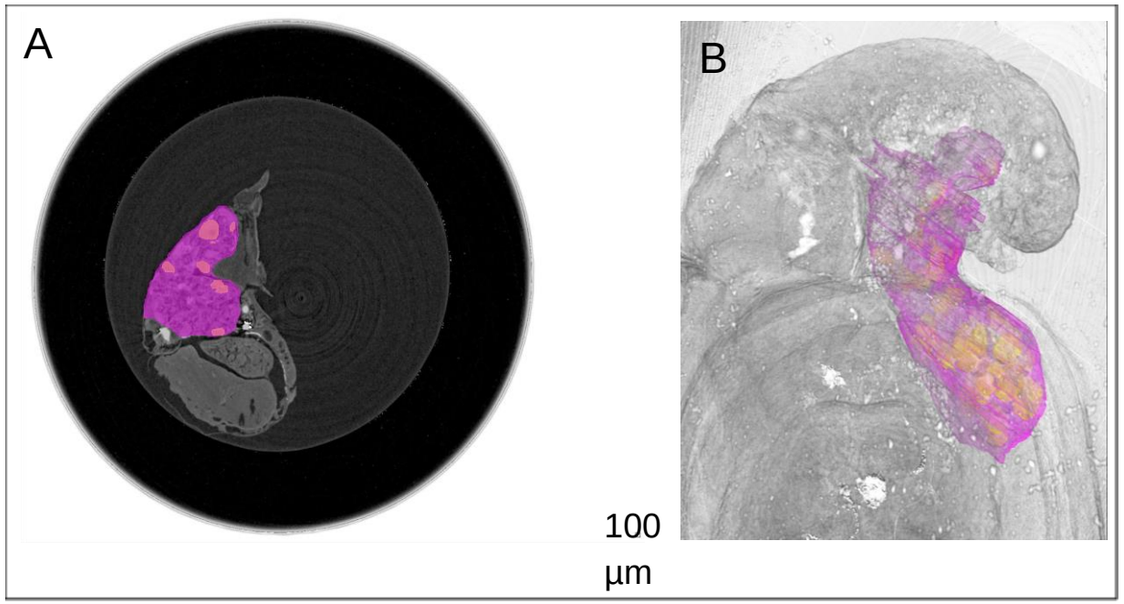
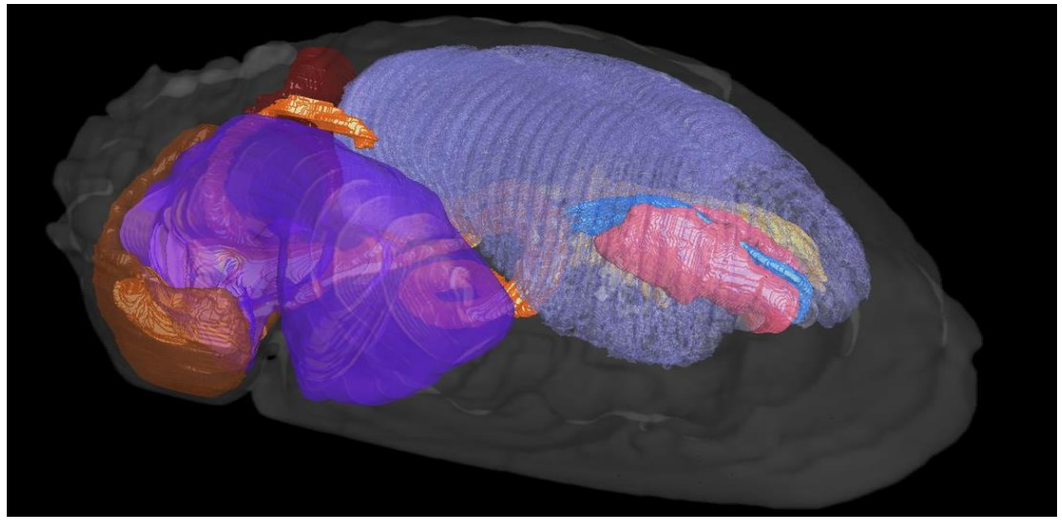
L’imagerie Synchrotron

La tomographie par rayonnement synchrotron est une technique - non destructrice - permettant d’obtenir une pile de coupes virtuelles 2D de la structure interne des individus, créant ainsi une visualisation 3D



A : Vue 2D de la segmentation de la gonade et des ovocytes
B: Vue 3D de la segmentation de la gonade et des ovocytes
En rose : la gonade, en jaune : les ovocytes



Représentation 3D d’un individu de l’espèce Peltospira smaragdina, *réalisée à l’aide du logiciel* Dragonfly

Travaux de Marjolaine Matabos et Clément Desreumaux

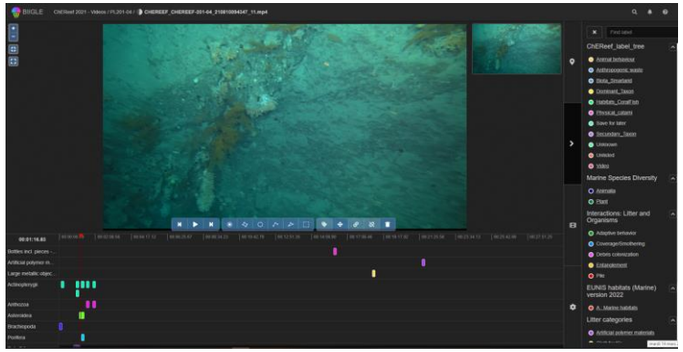
02.

Méthodes d’analyse d’images

Vers des approches automatisées

Annotation manuelle

Exemple du logiciel BIIGLE



First step: primary identification at low taxonomic level (by a deep-sea ecologist)

Phylum, class, order (super-family) levels

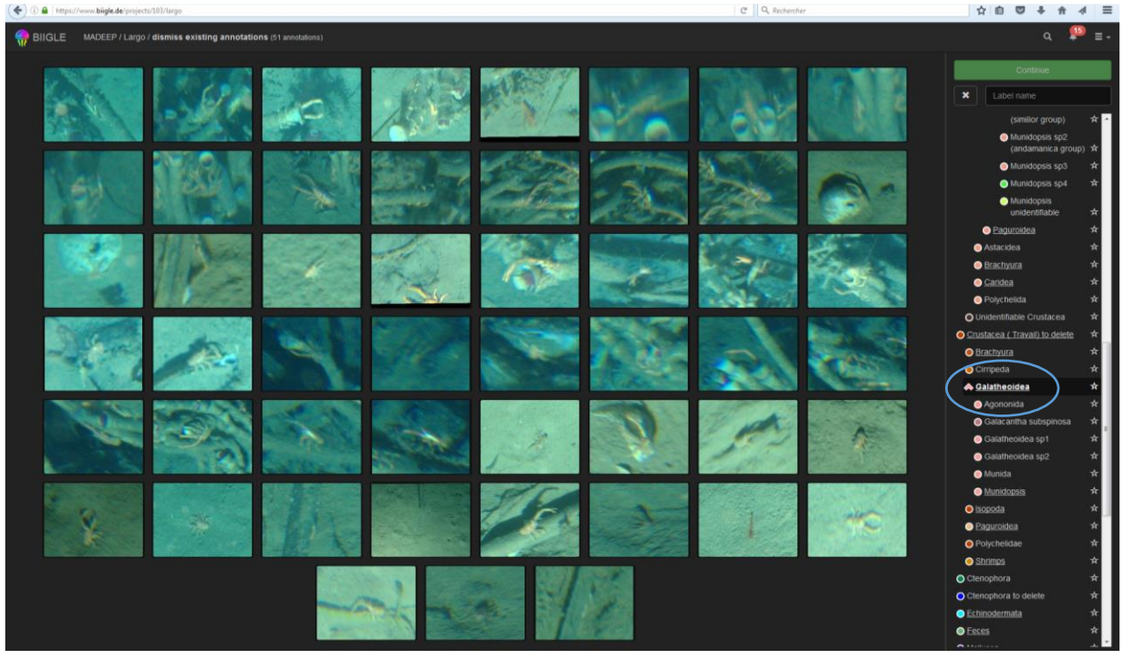
BIIGLE

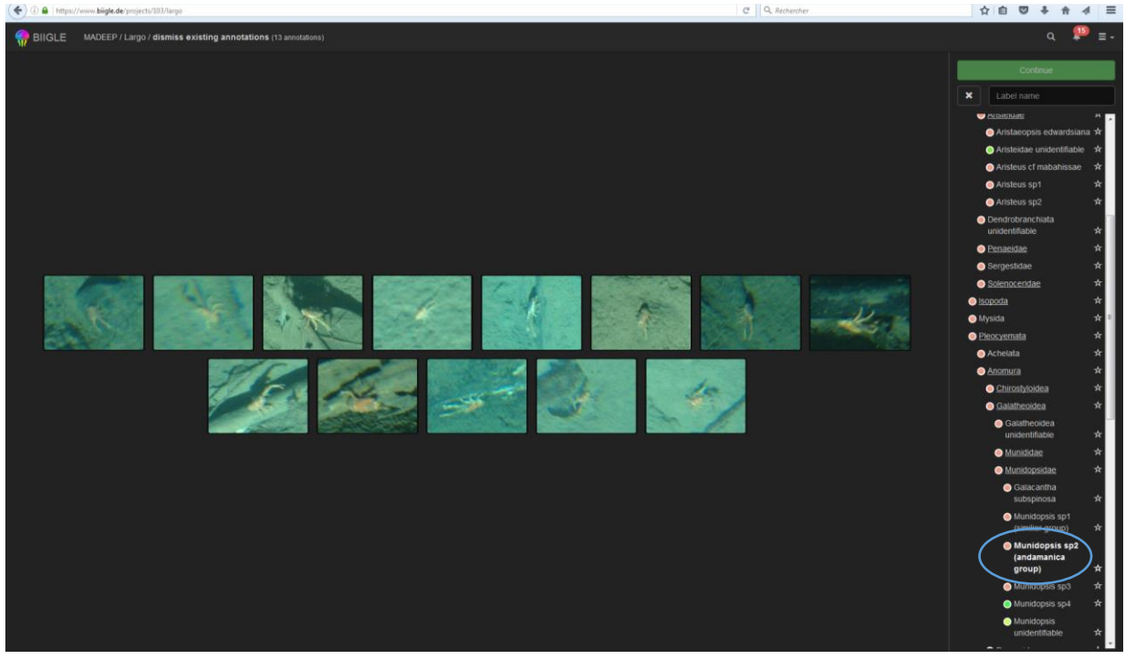
Annotation manuelle

Exemple du logiciel BIIGLE

Improvement of taxonomic identification by experts

Family, genus (species) levels
Morphospecies





For example: a selection with Largo tool on Galathoidea

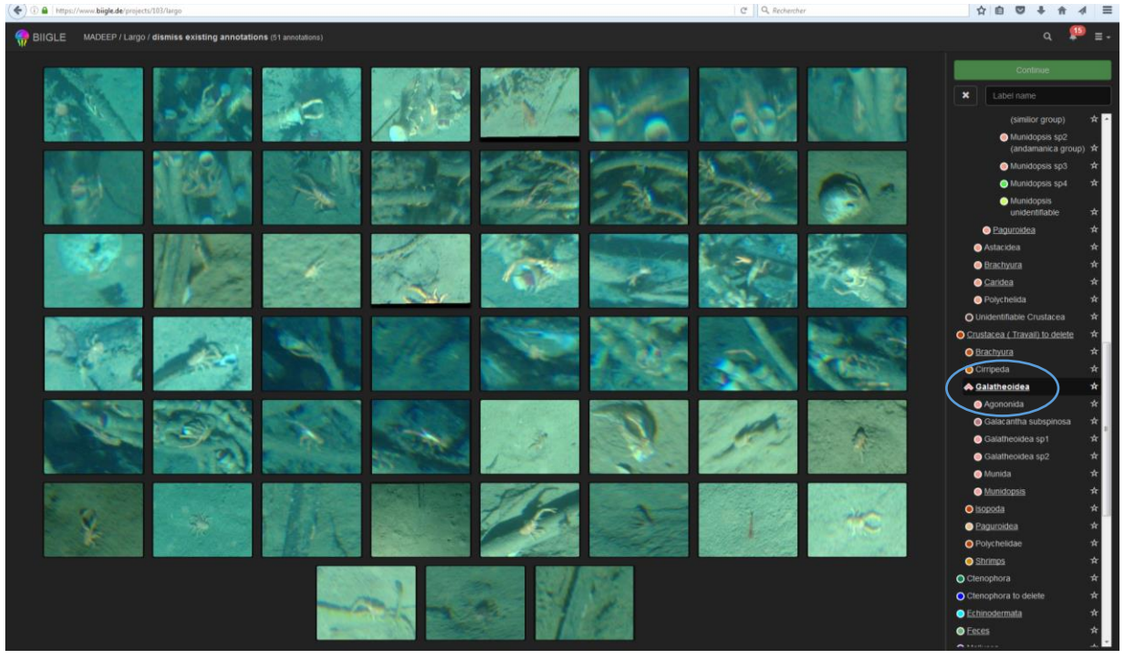
Annotation manuelle

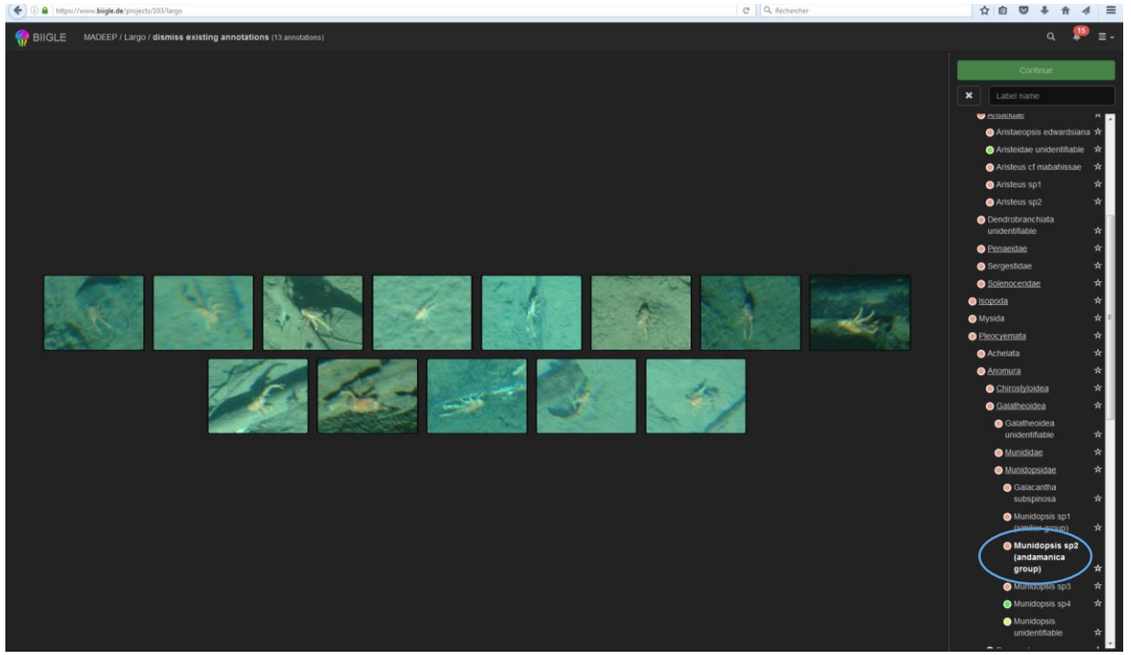
Exemple du logiciel BIIGLE

+ BIIGLE YOLO Active Learning

Improvement of taxonomic identification by experts

Family, genus (species) levels
Morphospecies





For example: a selection with Largo tool on Galathoidea

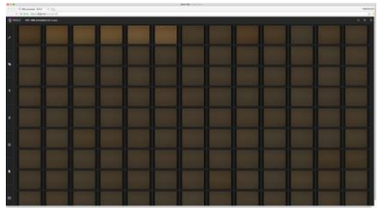
Fonctionnalités d'aide à l'annotation basées sur la vision par ordinateur

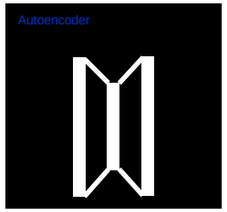
Exemple du logiciel BIIGLE

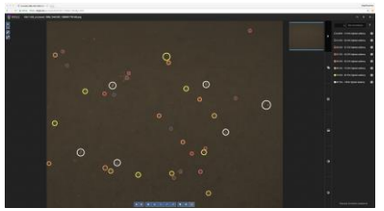
Use MAIA or Magic SAM to tackle the ever growing volume of unannotated images in environmental monitoring and exploration.

Example of MAIA output

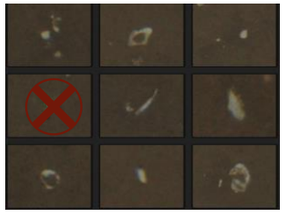
Unsupervised Detection with autoencoder Network



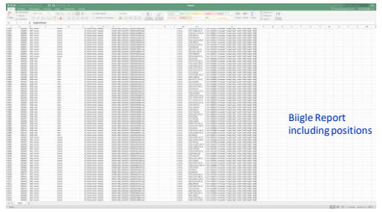


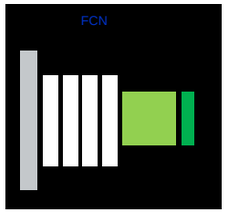


Human observer assistance



Fully convolutional network (FCN) [1] learning (5-40h on NVIDIA Titan X) and application





1 sec / image

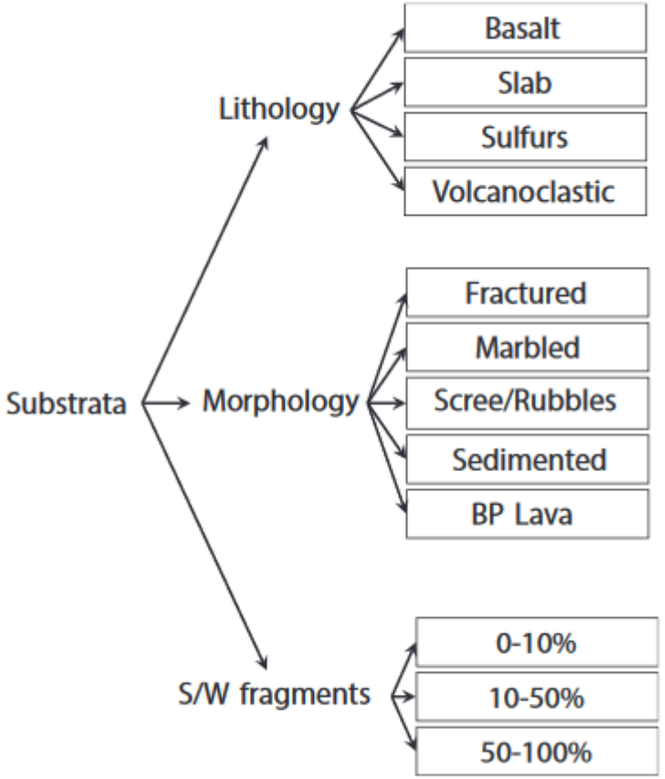
semantic segmentation (segmentation + label for every pixel) red=> animal, blue => shell

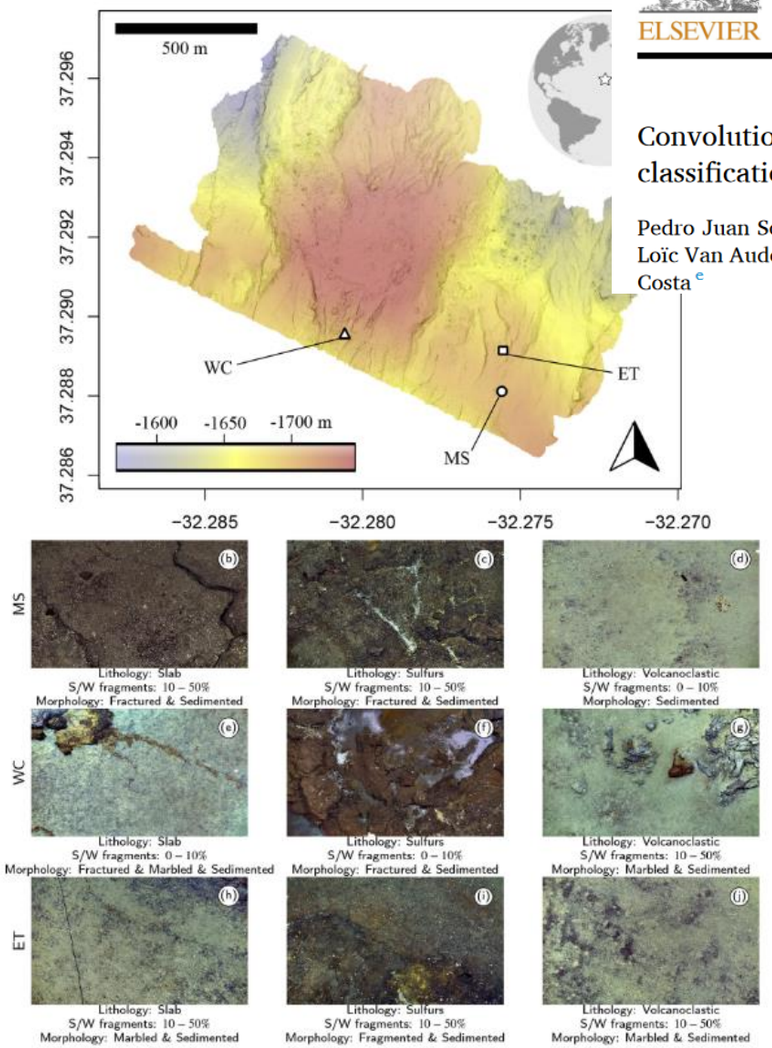
[1] Long, J et al. "Fully convolutional networks for semantic segmentation." *CVPR*. 2015.

Biodata Mining Group
Bielefeld University

Classification de substrats

Collaborations
IMT-A & ISEN





Contents lists available at ScienceDirect
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journal homepage: www.elsevier.com/locate/ecolinf

Convolutional neural networks for hydrothermal vents substratum classification: An introspective study

Pedro Juan Soto Vega [a,*], Panagiotis Papadakis [b], Marjolaine Matabos [c], Loïc Van Audenhaege [c,d], Annah Ramiere [c], Jozée Sarrazin [c], Gilson Alexandre Ostwald Pedro da Costa [e]

3DMASC: ACCESSIBLE, EXPLAINABLE 3D POINT CLOUDS CLASSIFICATION. APPLICATION TO BI-SPECTRAL TOPO-BATHYMETRIC LIDAR DATA.

Mathilde Letard[1*], Dimitri Lague[1,2*], Arthur Le Guennec[1,3], Sébastien Lefevre[4], Baptiste Feldmann[1,2], Paul Leroy[1,2], Daniel Girardeau-Montaut[5] and Thomas Corpetti[3]
[1] Univ Rennes, Geosciences Rennes, UMR 6118 CNRS, France.
[2] Univ Rennes, Plateforme LiDAR Topo-Bathymétrique Nantes-Rennes, OSUR, UAR 3343 CNRS, France.
[3] LETG UMR 6554, CNRS, F-35000 Rennes, France
[4] IRISA UMR 6074, Université Bretagne Sud, F-56000 Vannes, France
[5] Johnson and Johnson
* Correspondence: dimitri.lague@univ-rennes1.fr, mathilde.letard@univ-rennes1.fr

High-resolution 3D mapping of cold-water coral reefs using machine learning

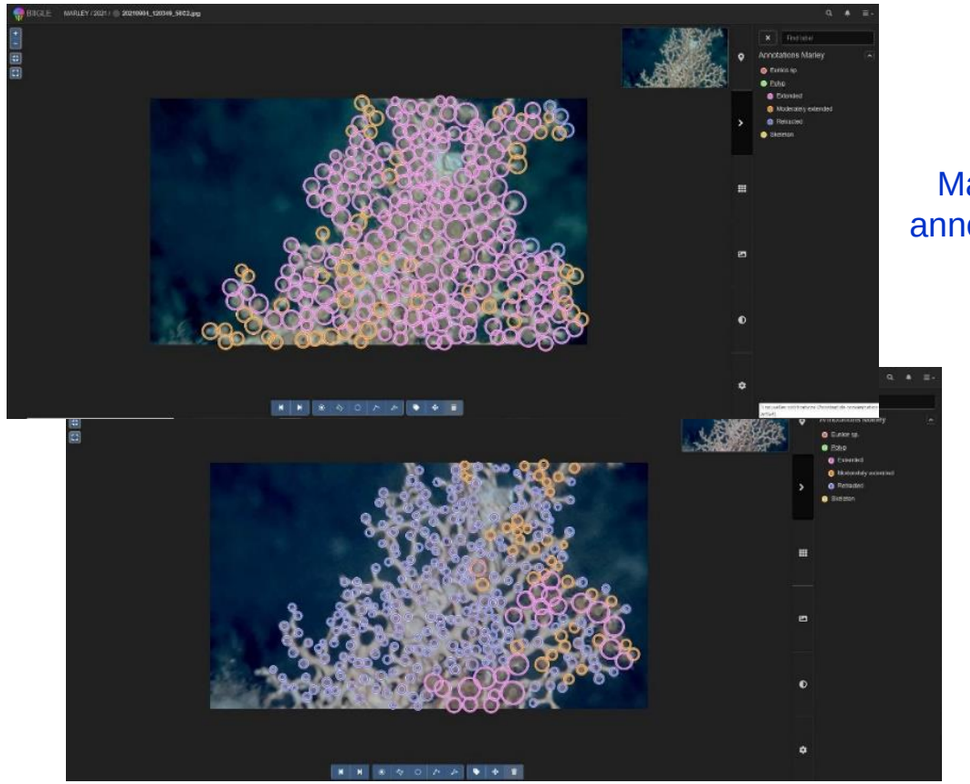
Larissa Macedo Cruz de Oliveira[1,2*], Aaron Lim[2,3], Luis A. Conti[4] and Andrew J. Wheeler[1,2,5]

[1]School of Biological, Earth and Environmental Science, University College Cork, Cork, Ireland, [2]Environmental Research Institute, University College Cork, Cork, Ireland, [3]Department of Geography, School of the Human Environment: Geography, Archaeology and Classics, University College Cork, Cork, Ireland, [4]Escola de Artes Ciências e Humanidades, Universidade de São Paulo, São Paulo, Brazil, [5]SFI Research Centre in Applied Geosciences, SFI Research Centre for Energy Climate and Marine, University College Cork, Cork, Ireland

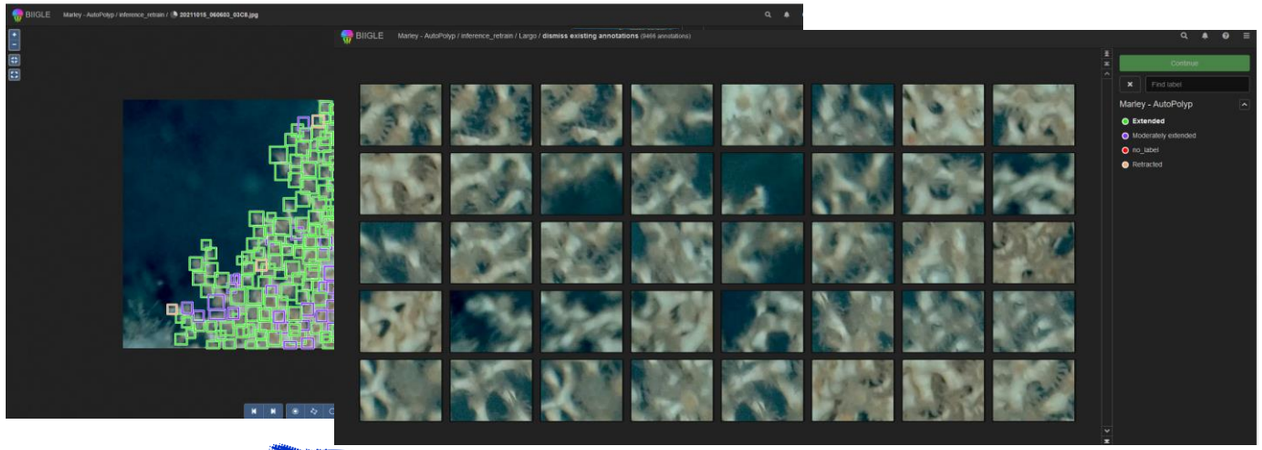
Analyse vidéo fixe

Exemple d'un jeu de données MARLEY

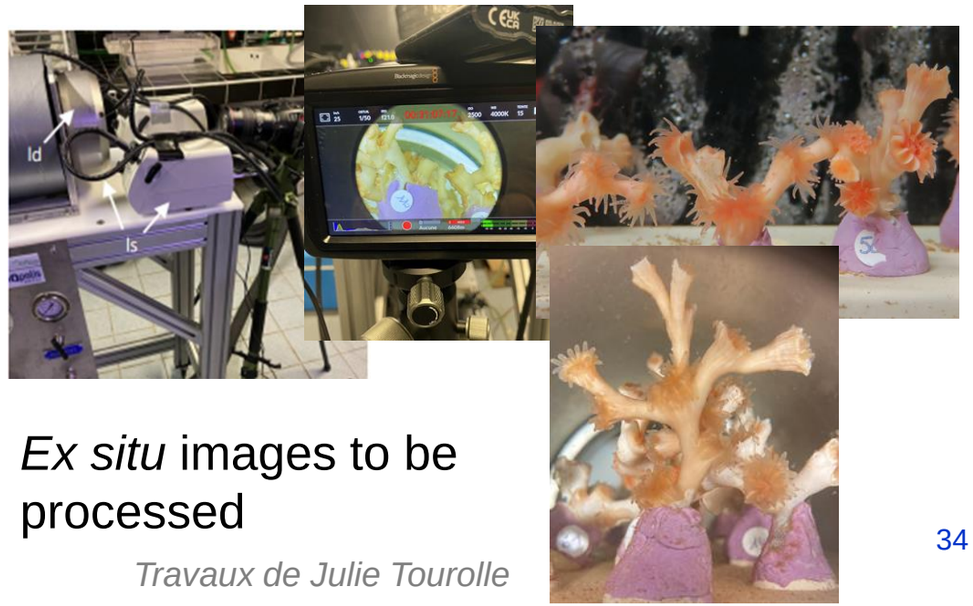
- Extraction of 1 image per video over 5 months of data, i.e. 540 images to annotate
- Manual annotation of 50 images to analyse the **behaviour of *Madrepora oculata* polyps** according to 3 states: extended / moderately extended / retracted, i.e. a total of 15,000 annotations
- Development of a **machine learning model** for polyp automatic annotation
- **200,000 polyps annotated and characterized**



Manual annotations



Automatic annotations



Ex situ images to be processed

Travaux de Julie Tourolle

Approche par les sciences participatives

ESPIONS DES OCÉANS par l'Ifremer

Volume colossal de données acquises (BIG DATA) qui nécessite de l'aide pour traiter les images acquises

- Avènement de l'intelligence artificielle (IA) a permis le développement d'algorithmes facilitant le traitement automatique de grands jeux de données
- Nécessité d'une phase d'apprentissage très chronophage !

Solution : impliquer les citoyens pour le traitement des données

- Approche basée sur le partenariat entre citoyen et chercheur
- Création de connaissance
- Contribution au développement technologique (méthodes d'IA)
- Sensibilisation du public à l'évolution des écosystèmes marins

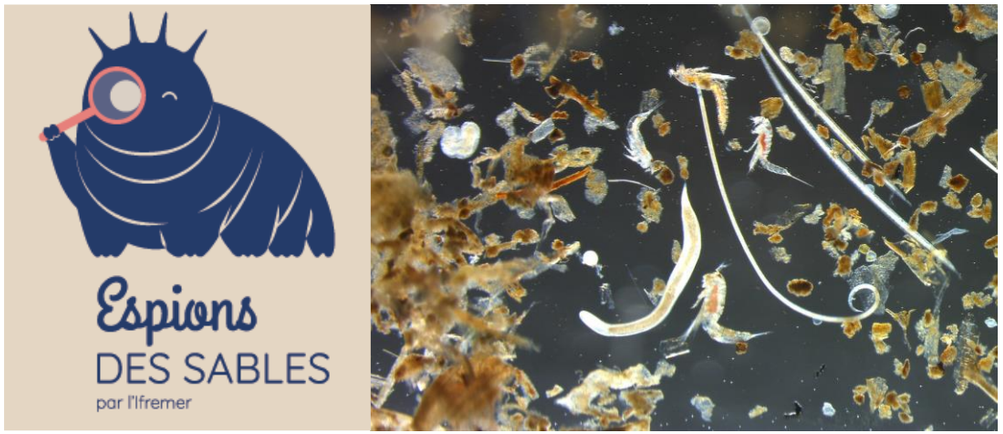
Espions DES GRANDS FONDS

Espions DES RÉCIFS PROFONDS

Ifremer

Approche par les sciences participatives

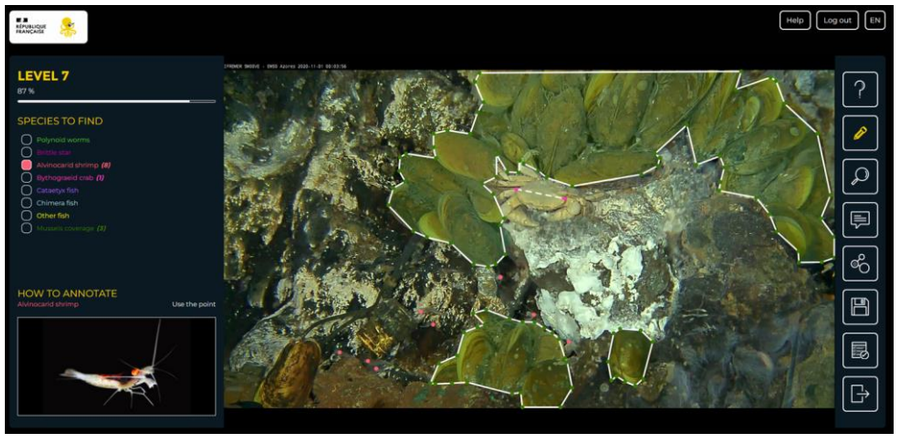
« Espions des Océans » offre le choix de participer à l'analyse des images des grands fonds mais aussi des récifs de coraux d'eau froide, de la Rade de Brest, des fonds de la Méditerranée…



Détection automatique d’espèces

Projet iMagine

- Citizen annotations from Deep Sea Spy, a participative science platform launched in 2017 giving access to EMSO-Azores and Ocean Networks Canada observatories images to be annotated by citizens.



Chimera fish
Bacterial mats
Other fish
Brittle star
Cataetyx fish
Mussels coverage
Bythograeid crab
Alvinocarid shrimp
Zoarcid fish
Tubeworms coverage
Polynoid worms (Atlantic)
Polynoid worms (Pacific)
Spider crab
Pycnogonid
Buccinid snail

- 4000 images, 15 species, 250000 annotations

This work is co-funded by the iMagine project (Horizon Europe) under Grant number 101017567.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TEMPO-MINI 2014-07-28 02:15:43

Détection automatique d’espèces

Projet iMagine

Yolov8 model

- CNN-based object detection model with fast processing of images, fast learning and high accuracy
- Ability to detect small objects in underwater video imagery, robust performance for analyzing various marine species

Training

- Training on cleaned citizen annotations from DeepSea Spy
- Validation on expert annotations when available
- Focus on *Buccinid* class on Ocean Networks Canada and *Bythograeid crab* on EMSO Azores

This work is co-funded by the iMagine project (Horizon Europe) under Grant number 101017567.

Détection automatique d'espèces

Projet iMagine

Publication of raw data/images, training datasets and pre-trained models on Seanoe (SEA scieNtific Open data Edition) + link in Zenodo (iMagine community):

https://doi.org/10.17882/101899
https://zenodo.org/records/13759095

The full pipeline is available on Github and on Docker Hub:

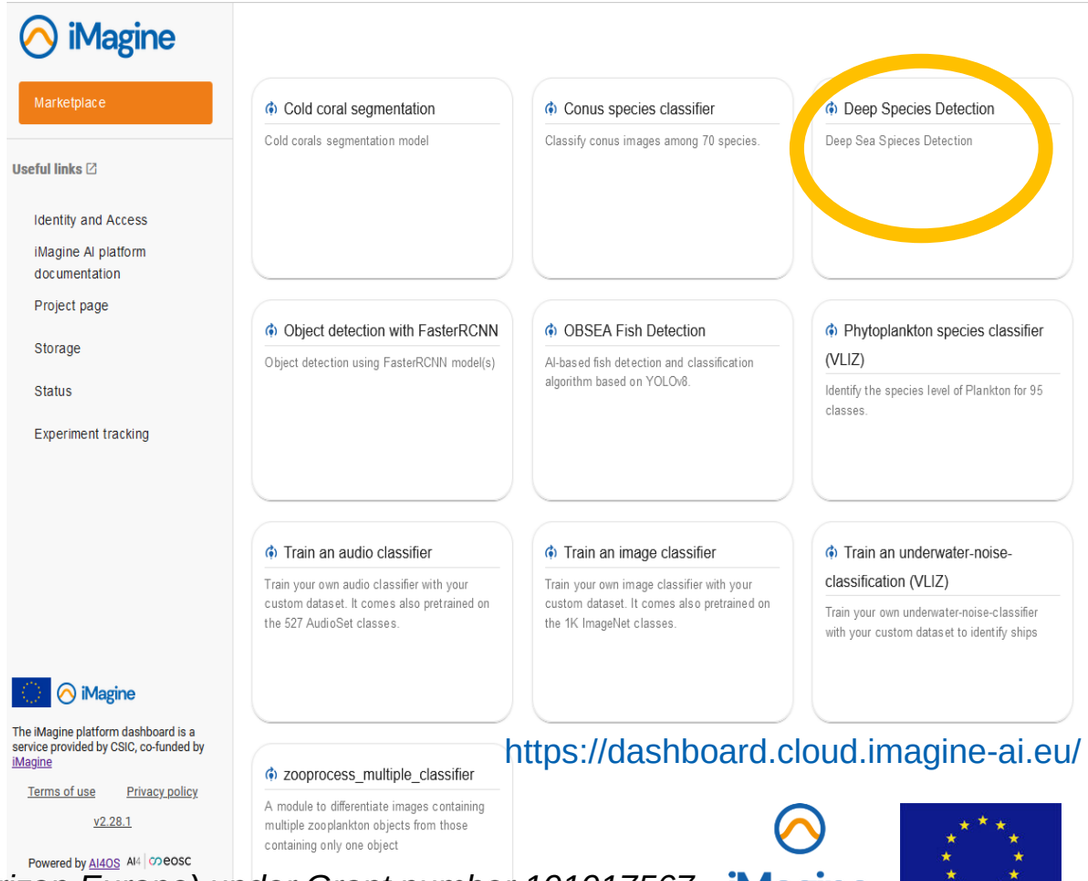
https://github.com/ai4os-hub/deep-species-detection
https://hub.docker.com/r/ai4oshub/deep-species-detection

The full pipeline can be run :

- using Jupyter notebook (interactive)
- in batch mode execution

Training and prediction can be done using Deepaas API

Can be used locally or in iMagine platform

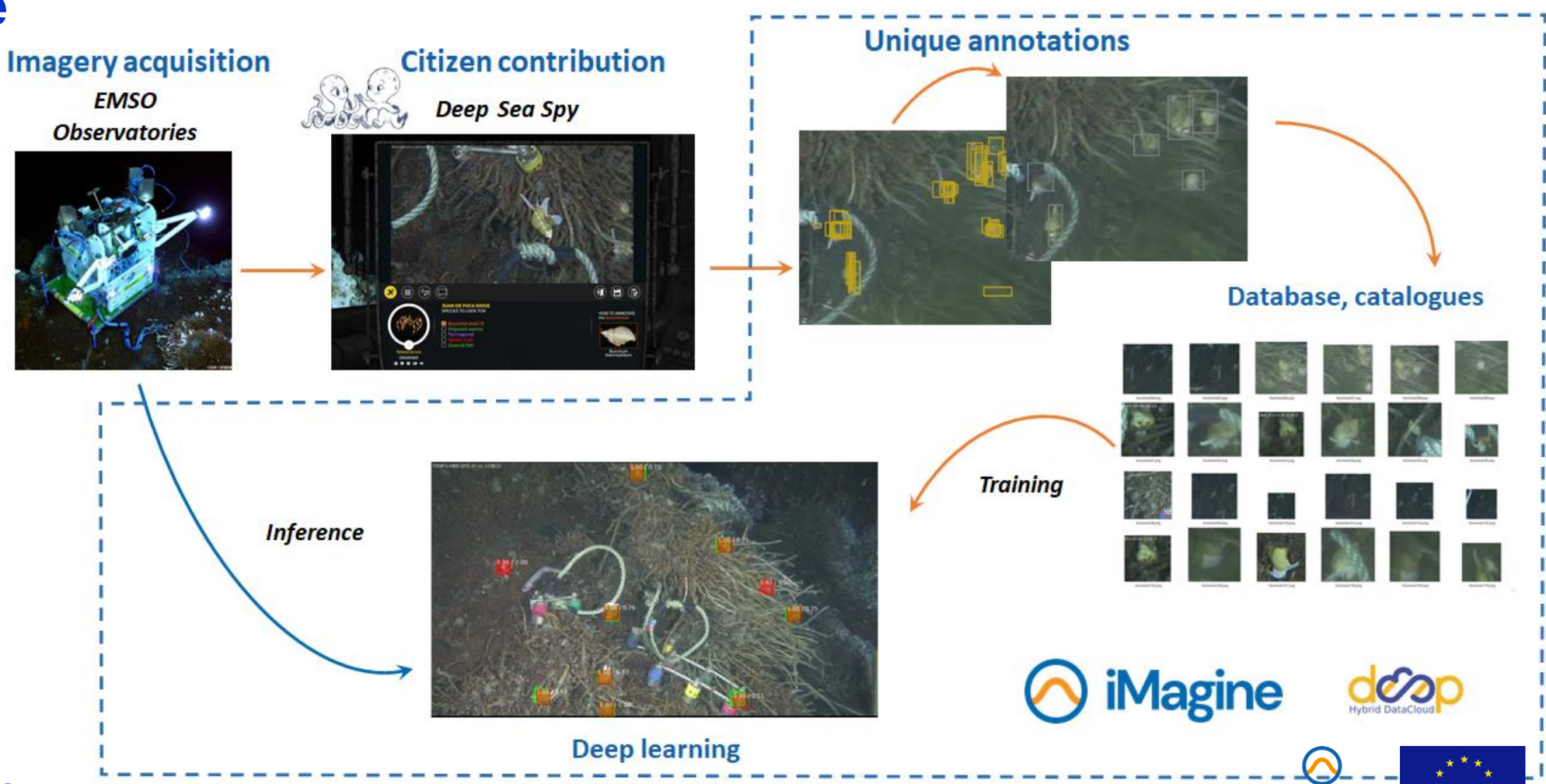


https://dashboard.cloud.imagine-ai.eu/

This work is co-funded by the iMagine project (Horizon Europe) under Grant number 101017567.

Détection automatique d’espèces

Projet iMagine



Perspectives

- Amélioration du modèle sur les classes buccins et crabes
- Entraînement sur d’autres classes
- Pipeline de pré-traitement peut être appliqué à tout type d’images

This work is co-funded by the iMagine project (Horizon Europe) under Grant number 101017567.

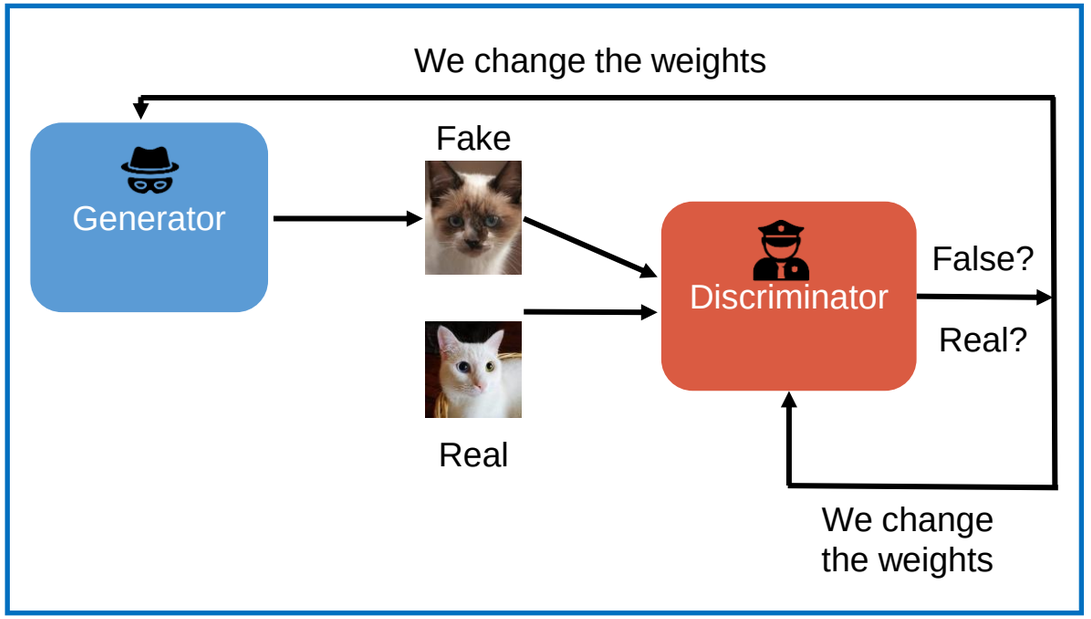
Blue Revolution – Cas de la méiofaune

Collaboration ENIB

Common issues:

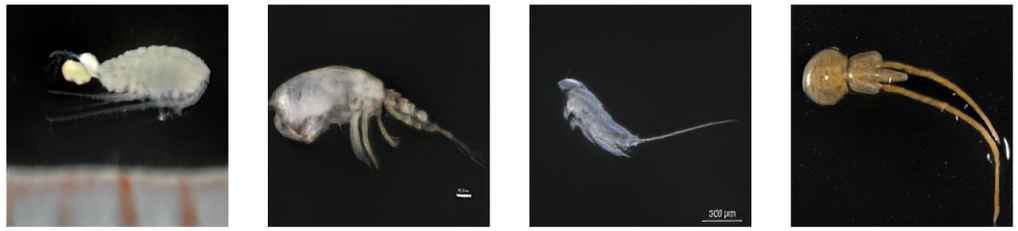
→ Limited labeled data in ecological studies
More information (higher quality data)
= more parameters to train
= more data are needed to train

→ Class imbalance
→ Unlabeled data



Generative Adversarial Network (GAN)

Artificial intelligence technique allowing to generate imitations of images, this approach was used on **copepods**

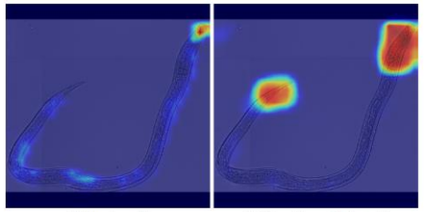


Examples of synthetic Copepoda images generated

Le projet BLUE REVOLUTION a été soutenu par le projet ISblue "Interdisciplinary graduate school for the blue planet" co-financé par une aide de l'Etat gérée par l'Agence Nationale de la Recherche au titre du programme « Investissements d'avenir » intégré à France 2030, portant la référence ANR-17-EURE-0015

Blue Revolution – Cas de la méiofaune

Knowledge guided machine-learning



(a) Simple model (b) Knowledge guided model

- 2D images **nematodes** dataset
- At genus level, aiming to enhance classification speed and accuracy
- Initially: classic supervised deep learning models for image classification
- To address the limited biological data available: **integration of expert taxonomist knowledge**

→ knowledge-guided machine learning model with a new loss function, encouraging the model to focus on important species features (head and tail)

Mohammad Aryayi's work



Semi-supervised deep learning models

- Focus on auto-classification of **copepoda**.
- Evaluation of the performance of several deep-learning models within both supervised and semi supervised learning frameworks. DenseNet201 consistently outperformed the other models, achieving the highest accuracy in both settings.
- In the supervised approach, DenseNet201 reached an accuracy of 68.90%. However, by **incorporating unlabeled data in a semi-supervised framework** and optimizing key parameters such (loss balancing factor λ and learning rate), the model's performance was significantly improved, achieving an accuracy of 82.41%.

Mahdieh Pouresmaeil's work

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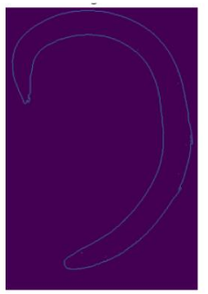
Blue Revolution – Cas de la méiofaune

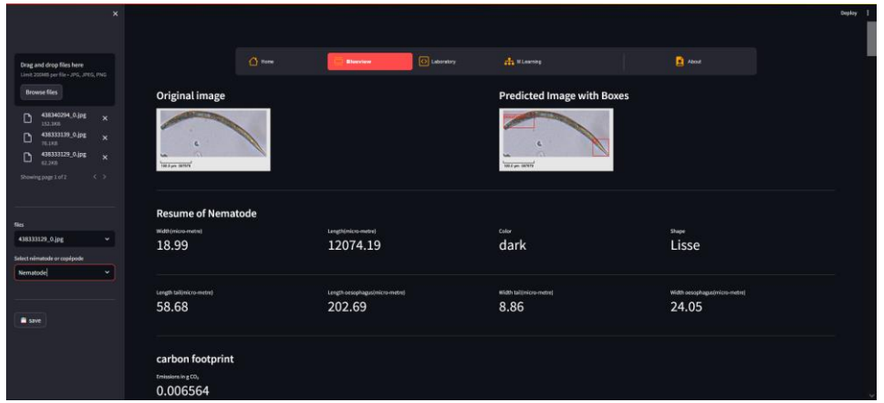


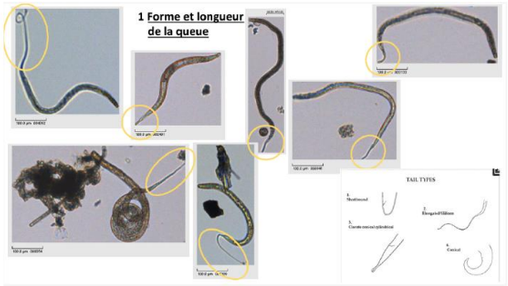
Collaboration ENIB

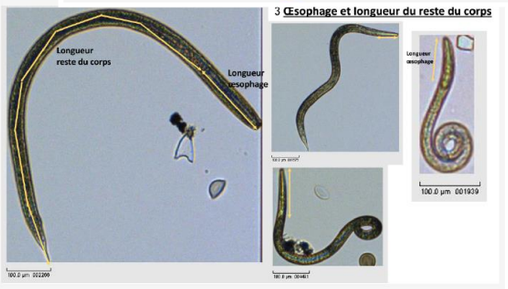
Traits measurement

Program based on traditional image processing or more complex AI algorithms, allowing for automatic annotation and measurement of morphometric features:

- ✓ Remove waste from microscopic images to separate nematodes
- ✓ Separate multiple elements
- ✓ Determine tail shape and length
- ✓ Determine width and length of individuals
- ✓ Determine the ratio of oesophagus length to the length of the rest of the body
- ✓ Classify images according to nematode colors: dark or light
- ✓ Determine whether the body is smooth or irregular
- ✓ Classify images according to coiling threshold
- ✓ Detect the presence of gonads and calculate their lengths and widths







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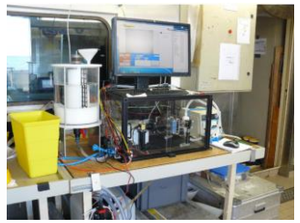
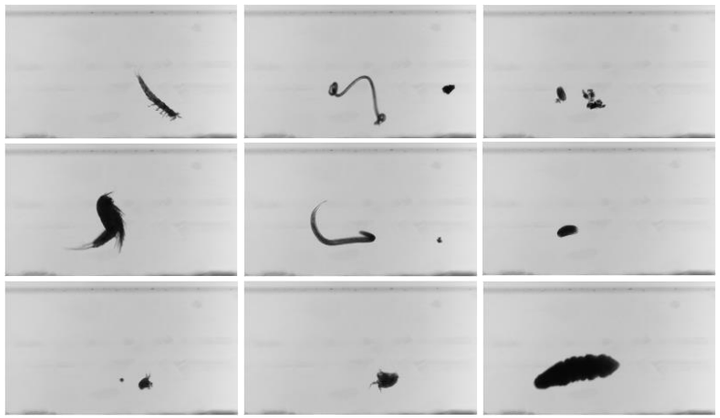
Blue Revolution – Cas de la méiofaune

EcoTaxa





Thumbnails & objects properties

EcoTaxa 2.0

Automatic classification/prediction
& Manual annotation/validation

- COLLABORATIVE annotation via WEB interface (all successive annotations are recorded)
- OPTIMIZED for large datasets
- USES classification tools to assist taxonomist classifying large datasets (RF & DL)
- ECOTAXA can easily import image datasets from any instrument

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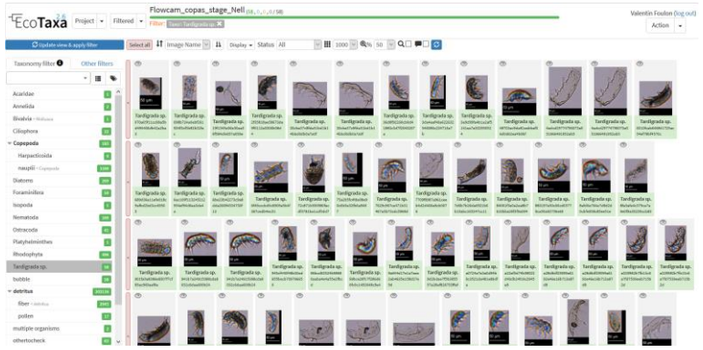
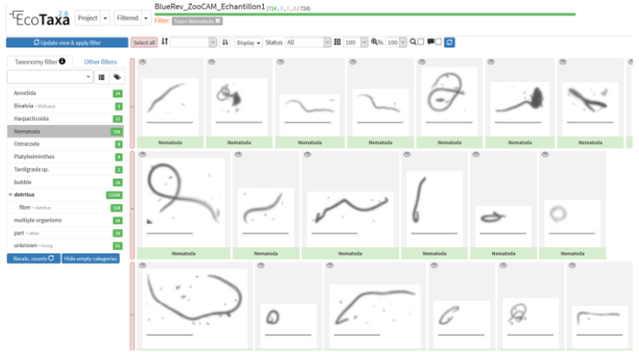
Blue Revolution – Cas de la méiofaune

EcoTaxa





Objective: Use EcoTaxa to automatically classify objects from flow imaging of meiofauna and assist the users for the creation of the learning sets and the validation of the identification proposed by the classification algorithm

Challenges with meiofauna images!

- → Lot of detritus
- → For big datasets it would be needed to work « outside » EcoTaxa
- → Will need adding new deep-learning algorithms for meiofauna classification

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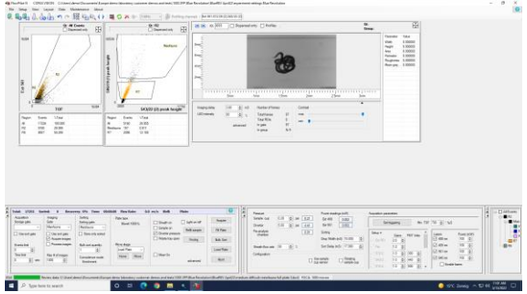
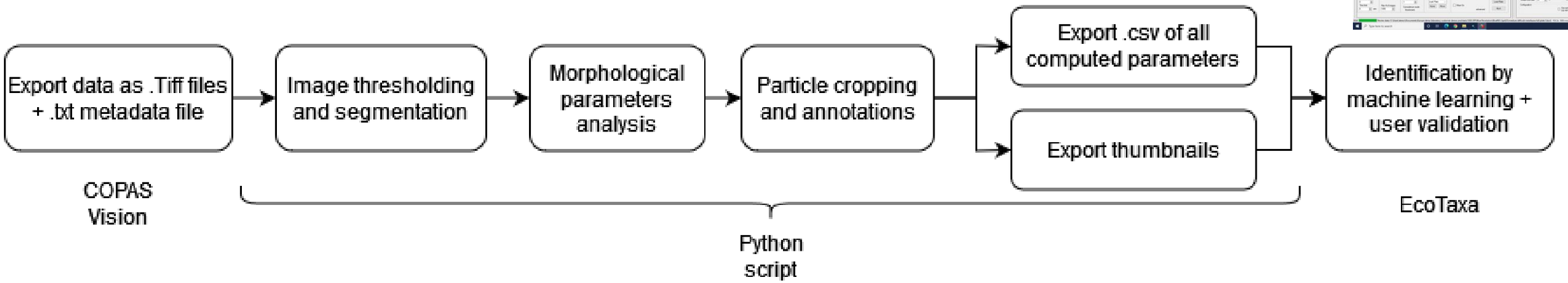
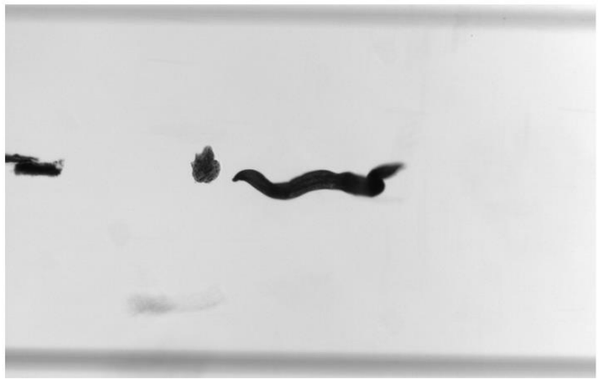
MEIODYSSEA – Cas de la méiofaune
COPAPP

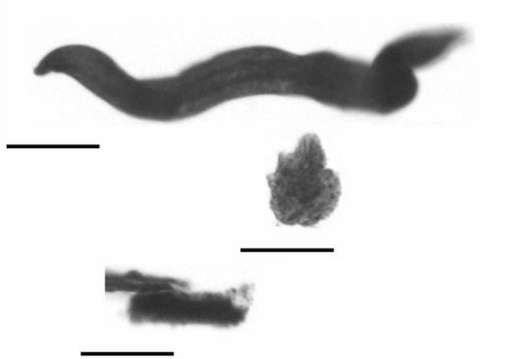






Raw .Tiff file

Processing

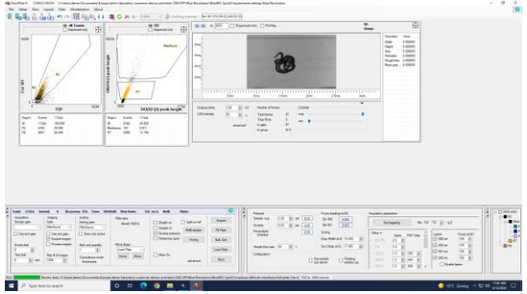


Segmented particles for EcoTaxa

The MEIODYSSEA project is supported by the Ocean Shot Research Grant Program.

MEIODYSSEA – Cas de la méiofaune

COPAPP



Export data as .Tiff files + .txt metadata file

Image thresholding and segmentation

Morphological parameters

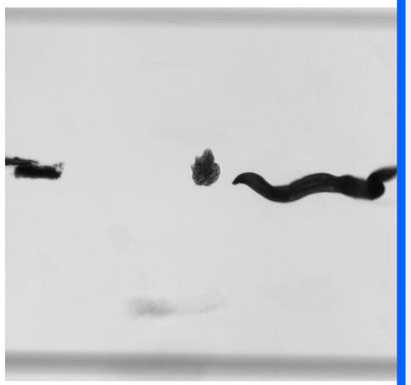
Particle cropping and annotations

Export .csv of all computed parameters

Identification by machine learning + user validation

COPAS Vision

EcoTaxa



Raw .Tiff file

EcoTaxa

app

File Edit View Window Help

About the script

This script has been specifically written to process and analyze images taken by the COPAS Vision 1000 as part of the Meiodyssea project.

Visit our gitLab repository:

GitLab Meiodyssea repository

Technical information

- The scale bar corresponds to 100µm.
- Each pixel corresponds to 1.38µm.
- Circularity parameter is computed as follows:

$$f = \frac{4\pi A}{P^2}$$

P = Perimeter of the particle
A = Area of the particle

Contact

Lou-Hannah Dichant
lou.hannah.dichant@ifremer.fr

Valentin Foulon
valentin.foulon@enib.fr

Deep-sea Laboratory - IFREMER
1625 route de Sainte-Anne
29800 PLOUZANE

COPAS Vision Data Processing

Choose analysis mode:

- (•) Single Folder Analysis
- ( ) Multiple Folders Analysis

Mandatory fields

Enter working directory:

Sample name:

Threshold Value: 235 (0 – 255)

Minimum particle area to analyse (px): 200

Upload Background Image

Drag and drop file here
Limit 200MB per file • TIFF, TIF
Browse files

[x] Are there numbers in the top left corner of your frames?

Additional fields

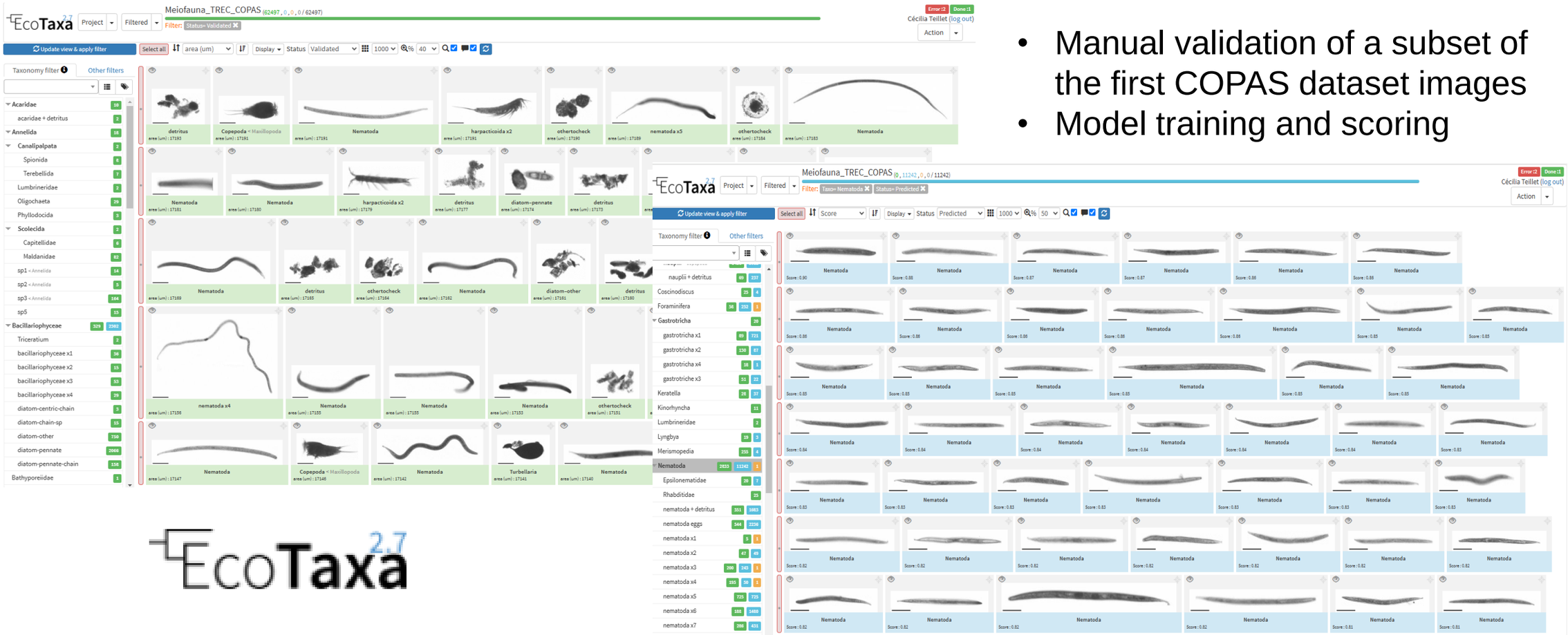
Sampling date (YYYY-MM-DD):

Sampling location:

The MEIODYSSEA project is supported by the Ocean Shot Research Grant Program.

MEIODYSSEA – Cas de la méiofaune

COPAPP



- Manual validation of a subset of the first COPAS dataset images
- Model training and scoring

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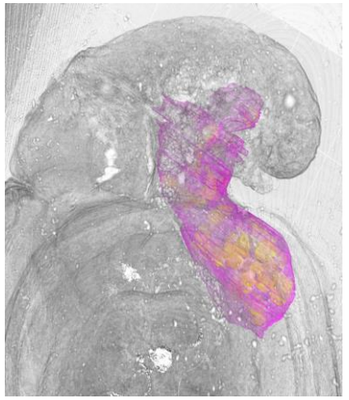
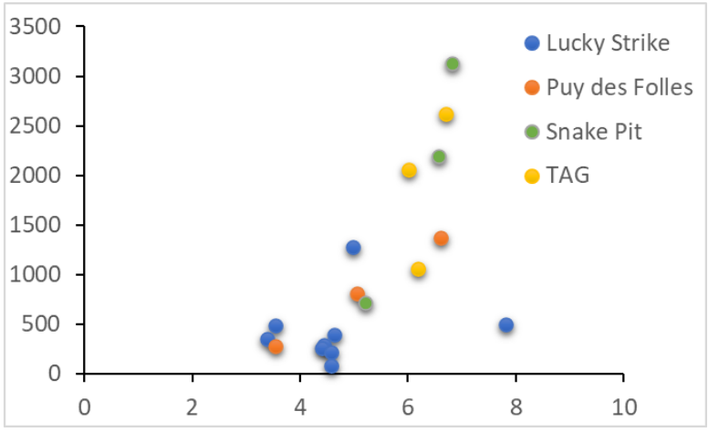
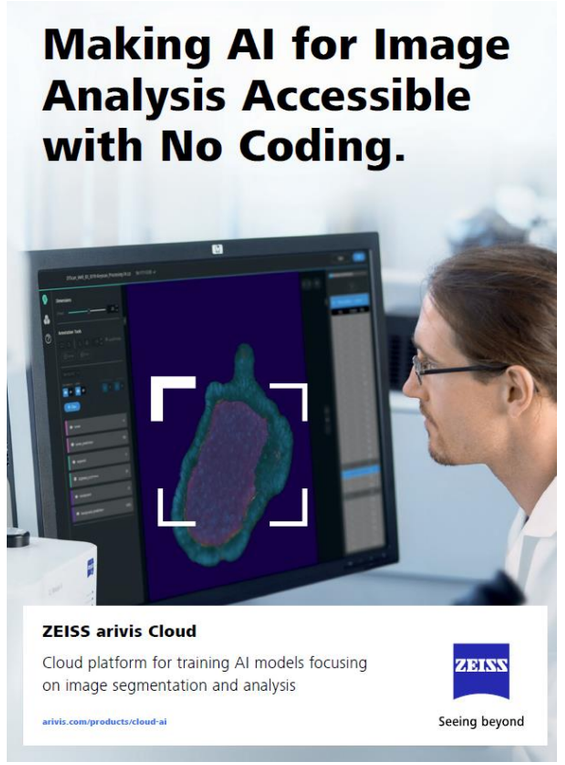
Annotation des images Synchrotron

- Recherche d’une méthode adéquate de segmentation
- Test de différents logiciels : ImageJ Fiji, Dragonfly et Arivis Vision4D
- Segmentation manuelle des ovocytes et de la gonade des individus grâce au logiciel Arivis Vision 4D
- Tests de deep-learning avec ces logiciels, sans succès



Gonade (rose) et ovocytes (jaune)



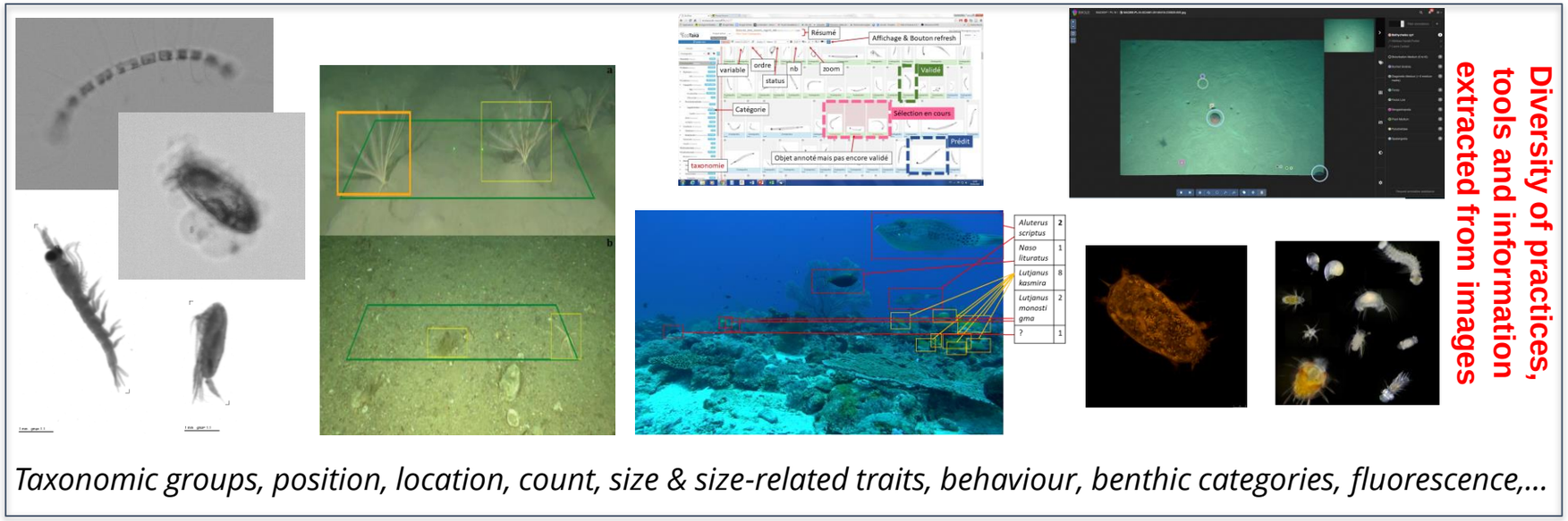


03.

Contextes national et international

Enjeux de standardisation et de partage

Challenges



Diversity of practices, tools and information extracted from images

Taxonomic groups, position, location, count, size & size-related traits, behaviour, benthic categories, fluorescence,…

Detection and contouring | **Identification/classification** | **Measurements**

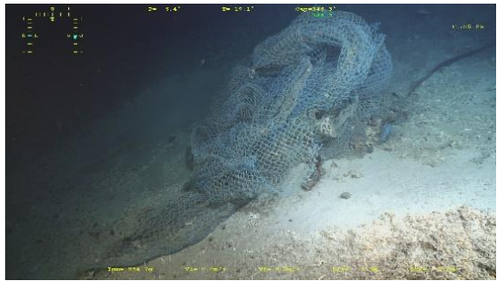
of organisms/habitats/objects

Standardization of methods, tools and annotated datasets

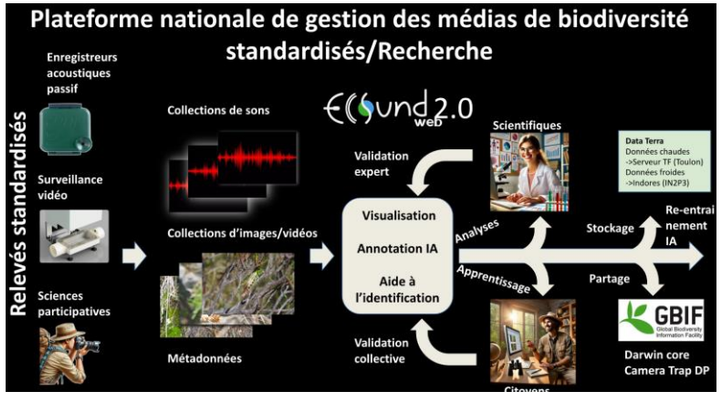
A.I. algorithms-based tools optimized for powerful results in interdisciplinary work on imagery

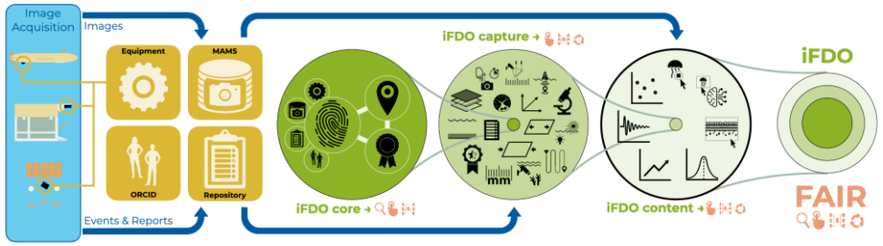
Serving **ecosystemic approaches & scientific questions on marine biodiversity**

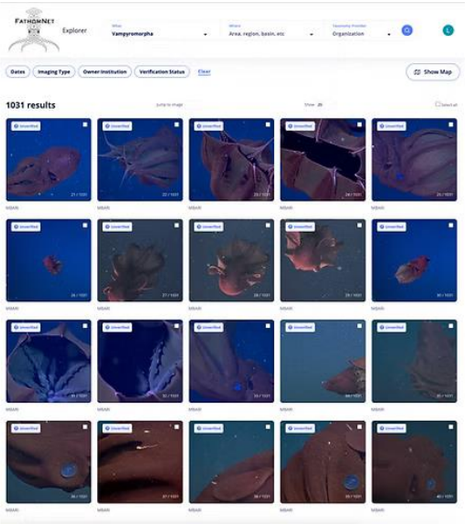
Initiatives nationales, européennes et internationales

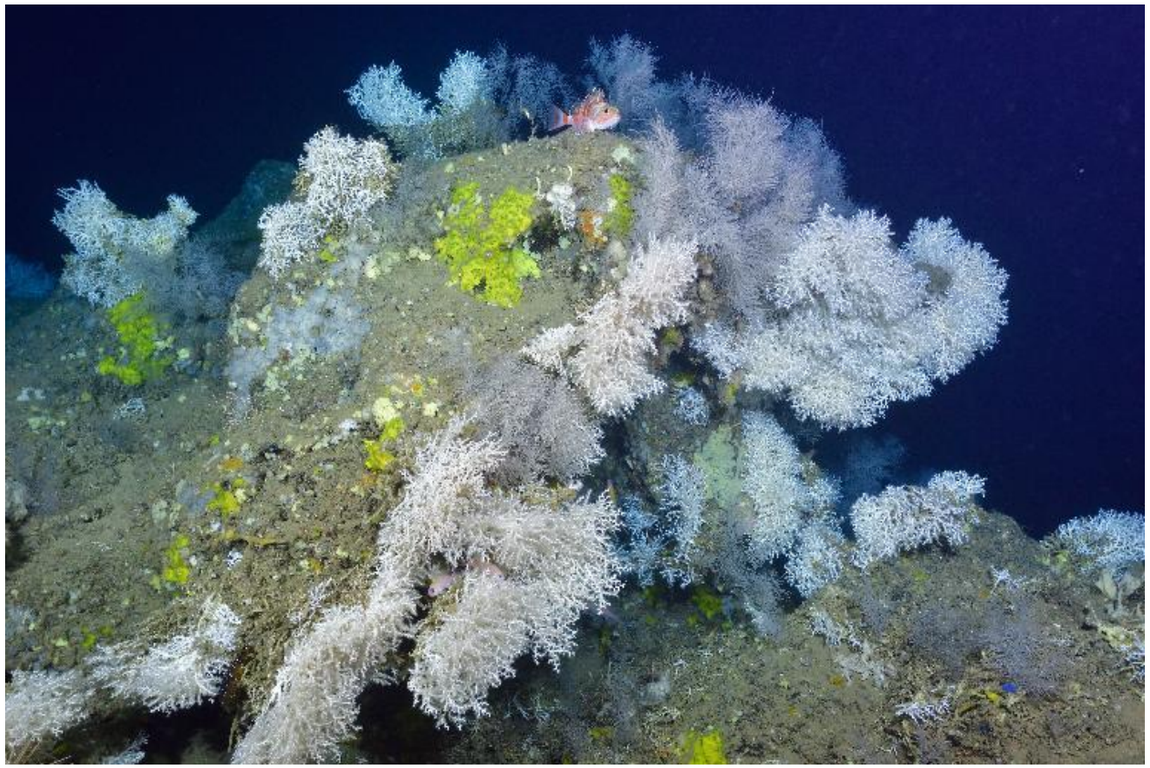


- ODATIS
- EcoInfoFAIR – BiomedIA
- imaginEcology (GDR Ecostat)
- iMagine & next
- Marine Imaging Workshop
- FathomNet
- Challenger 150 WG
- Quatre A









Merci pour votre attention