Thèse

Direction ….
Jury ….

STÉPHANE CHAVIN

NOVEMBER 6, 2026

METHODS FOR THE JOINT ANALYSIS OF SPECIES PRESENCE, FROM PASSIVE ACOUSTIC MONITORING, AND THEIR ENVIRONMENT

A large-scale, multi-year study of birds in Québec, Humpback whale in the Caribbean and Sperm whale in the Mediterranean Sea

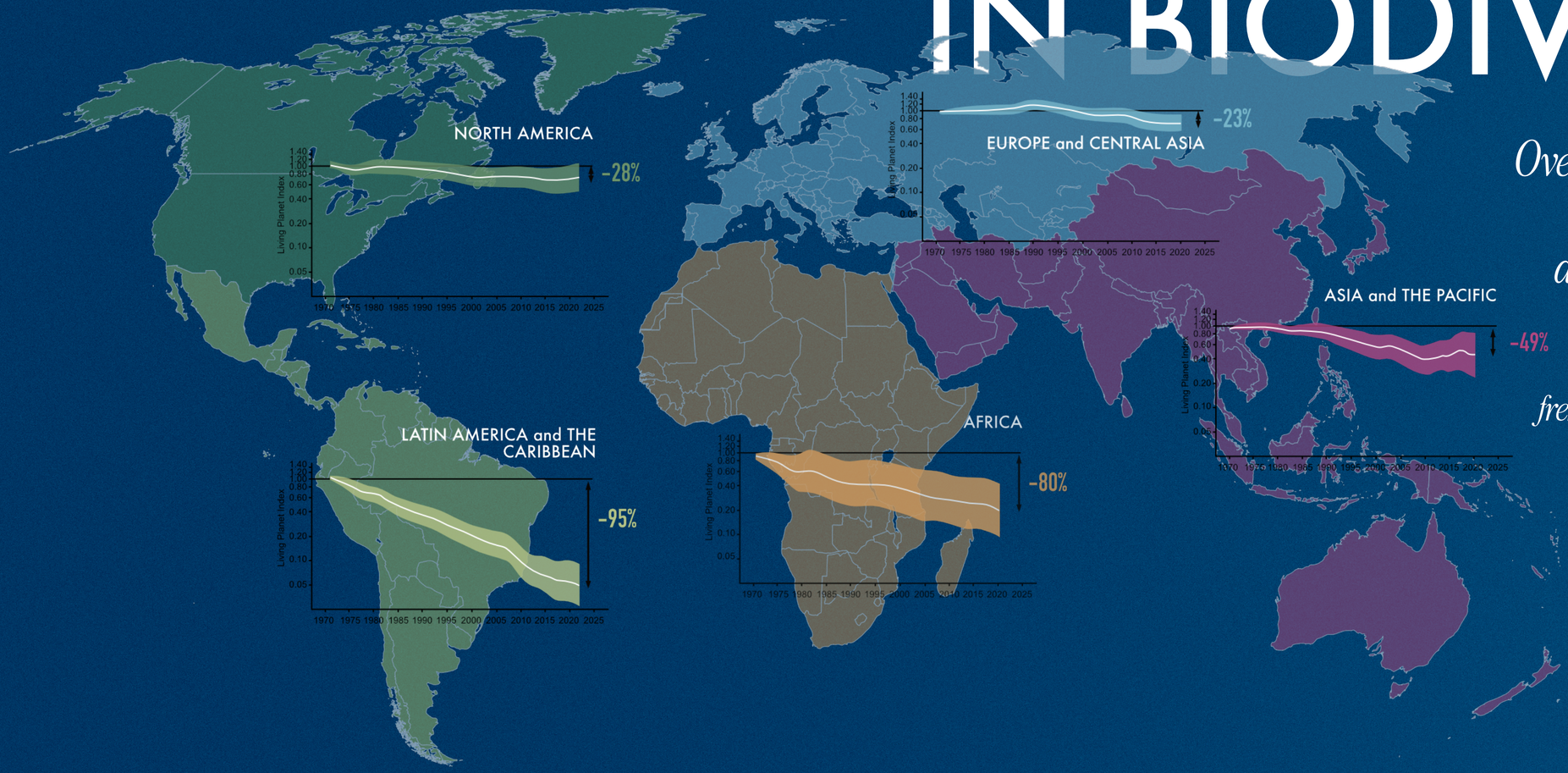
Mediterranean Institute of Oceanography

CENTRE int. d'INTELLIGENCE ARTIFICIELLE EN ACOUSTIQUE NATURELLE

UNIVERSITÉ DE TOULON

©Stéphane Chavin

A GLOBAL DECREASE IN BIODIVERSITY



Over the past 50 years, the size of the monitored population has decrease in average by 73% .

It represent a decrease of 85 % for freshwater, 69% for the terrestrial and 56% for the marine populations

- *Habitat destruction*

  ex : Clearing forests, converting wild lands for agriculture...

- *Overexploitation*

  ex : Overfishing

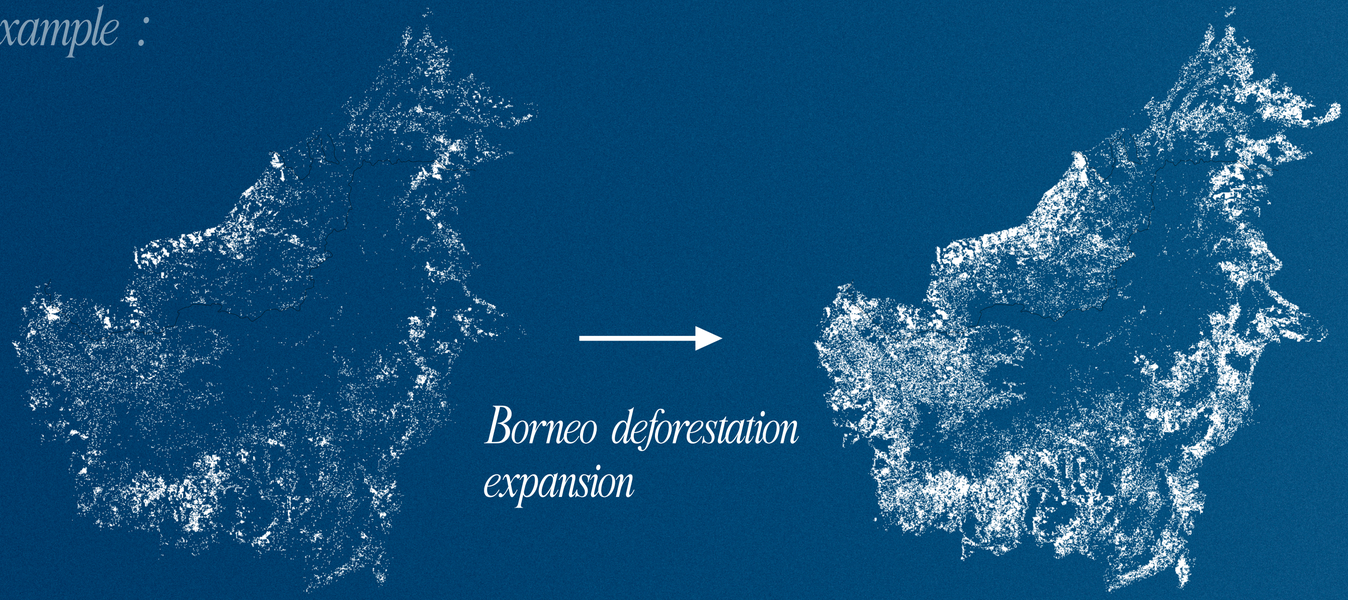
- *Climate change*

  ex : Changing seasonal fluctuation

- *Pollutions*

  ex : Plastics, chemicals, fertilizers...

example :



WHAT CAN SCIENCE DO ?

- *Monitoring*
  ex : eDNA, remote sensing, bioacoustics
- *Conservation strategies*
  ex : Habitat restoration, new protected areas
- *Systemic policy changes*
  ex : Nature driven governance, new laws to protect species



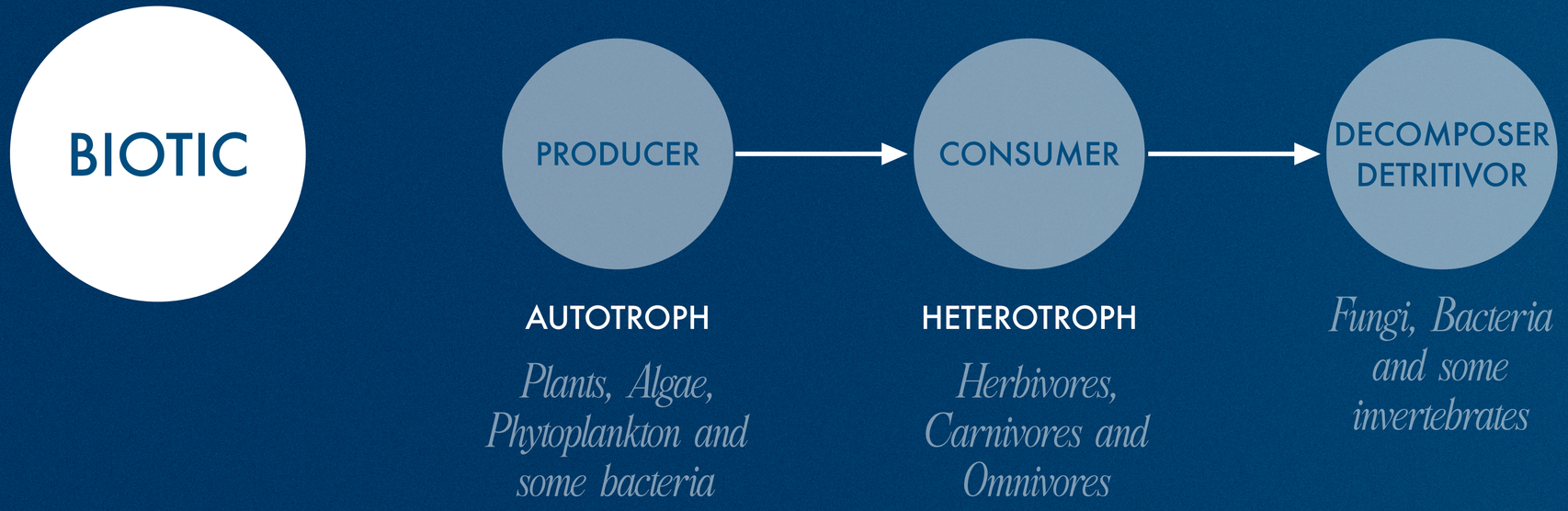
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THE ENVIRONMENT

BIOTIC + ABIOTIC

THE ENVIRONMENT

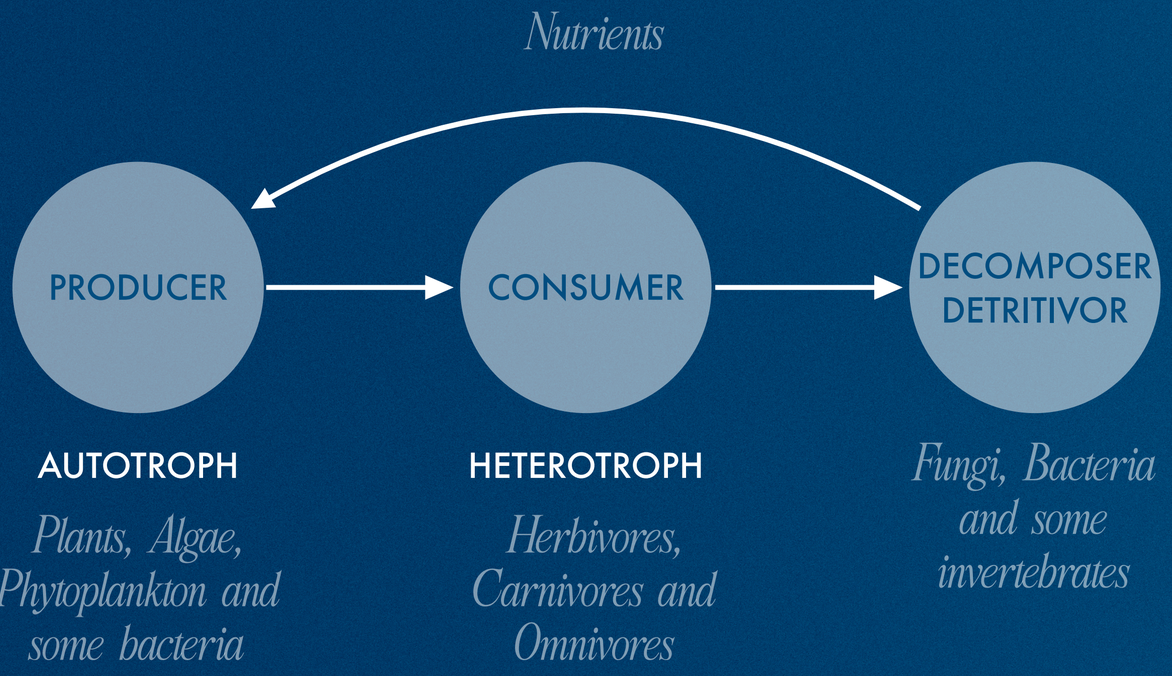
- *biotic component*



THE ENVIRONMENT

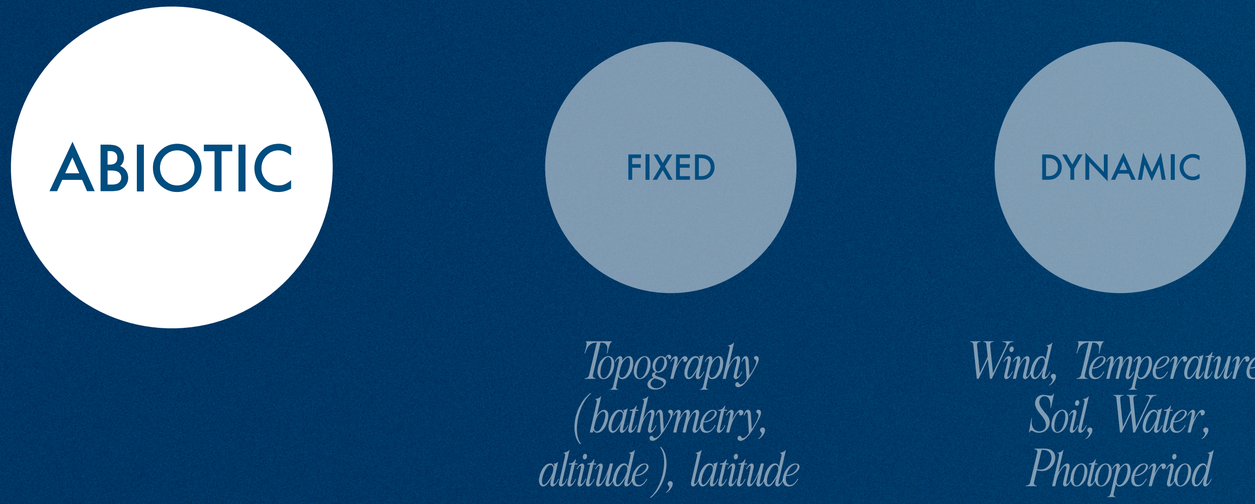
- *biotic component*

BIOTIC



THE ENVIRONMENT

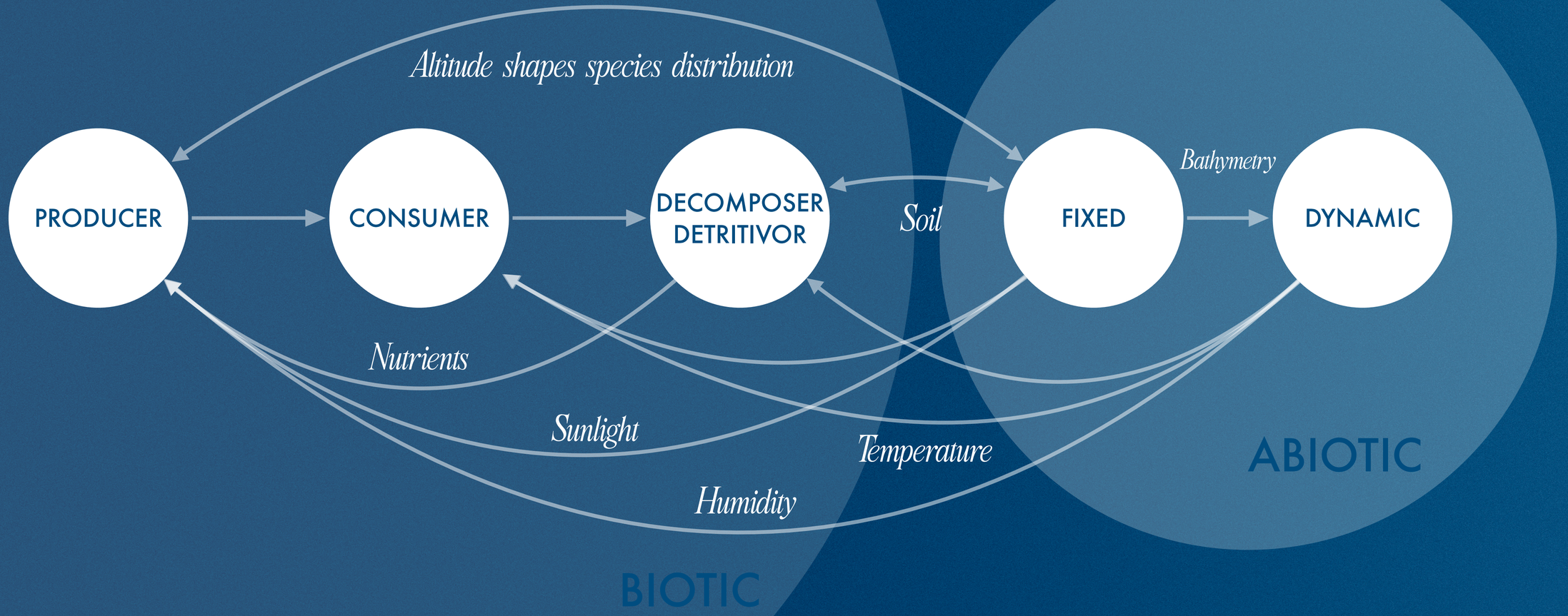
- *abiotic component*

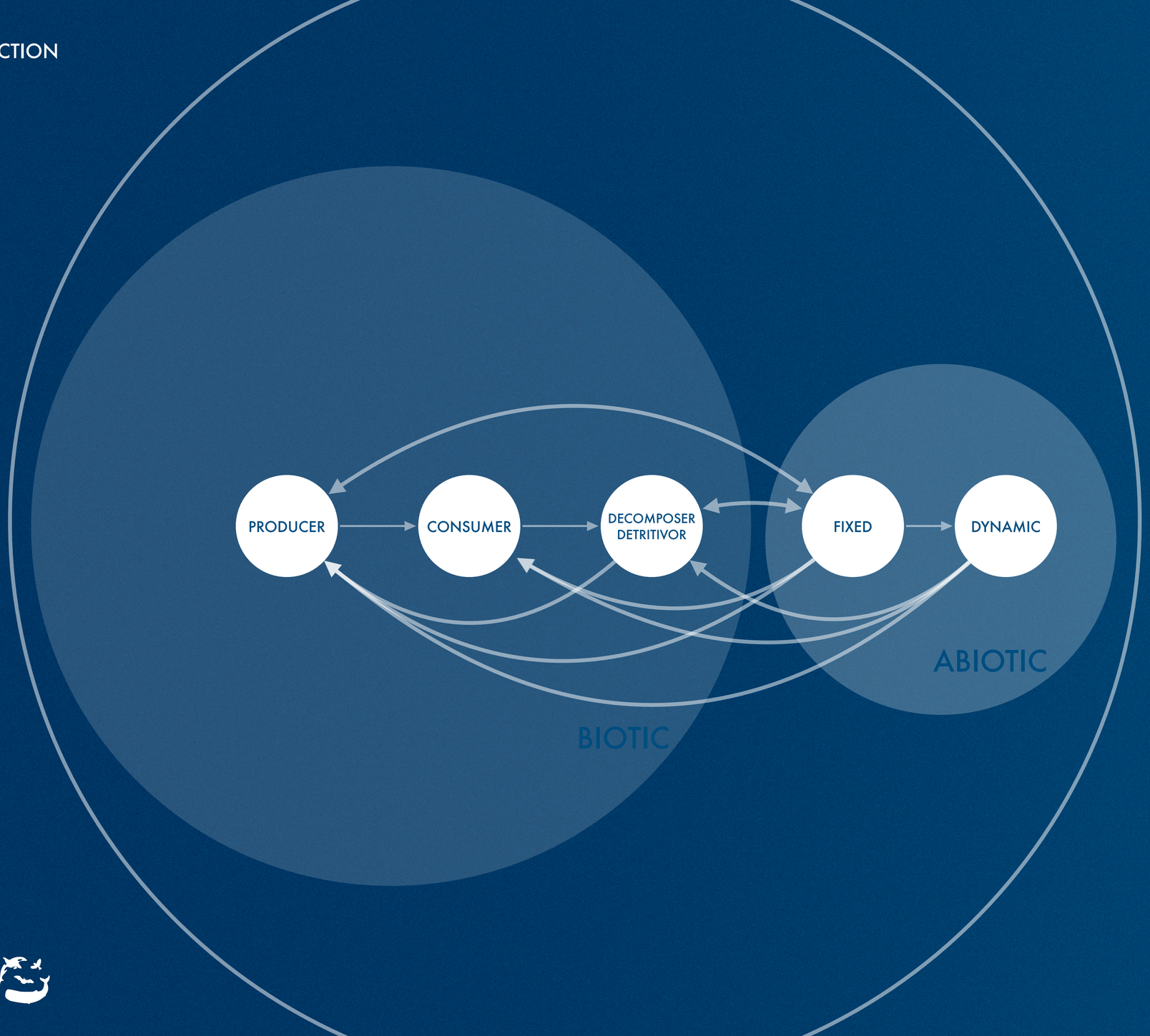


THE ENVIRONMENT

BIOTIC + ABIOTIC

THE ENVIRONMENT





= AN ECOYSTSEM

The interactions between living beings and their environments = interdependence of each one

→ *Influence*

CENTRE int. d'INTELLIGENCE ARTIFICIELLE en ACOUSTIQUE NATURELLE

WHAT WE HAVE TO DO ?

HOW ?

- *Monitoring*
  ex : eDNA, remote sensing, bioacoustics

→ Collecting data on field, searching for elusive or new species

- *Conservation strategies*
  ex : Habitat restoration, new protected areas

→ Identifying habitat, species preferences

- *Systemic policy changes*
  ex : Nature driven governance, new laws to protect species

→ Identifying the risks and presenting results and solutions

METHODS FOR THE JOINT ANALYSIS OF SPECIES PRESENCE, FROM PASSIVE ACOUSTIC MONITORING, AND THEIR ENVIRONMENT

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HUMPBACK WHALE

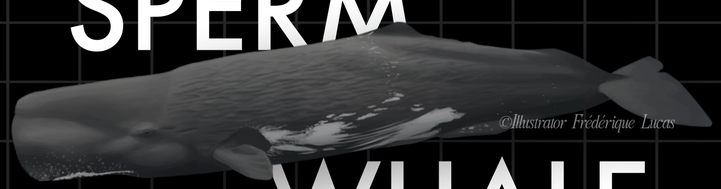


METHODS FOR THE JOINT ANALYSIS OF SPECIES PRESENCE, FROM PASSIVE ACOUSTIC MONITORING, AND THEIR ENVIRONMENT

HUMPBACK WHALE



SPERM WHALE

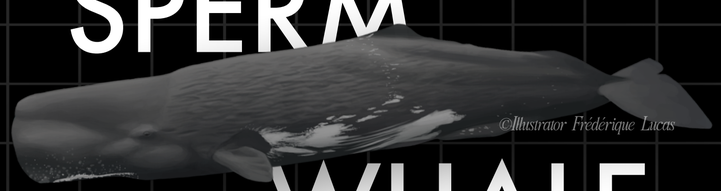


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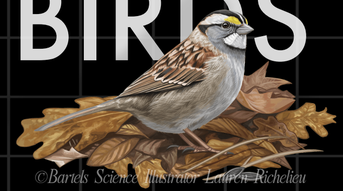
HUMPBACK WHALE



SPERM WHALE



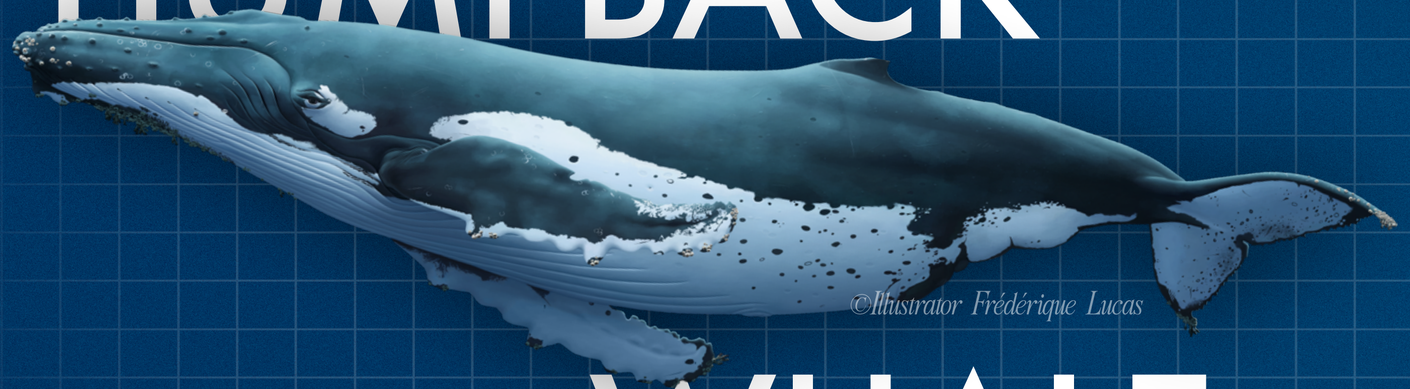
BIRDS



- *some context about*

HUMPBACK WHALE

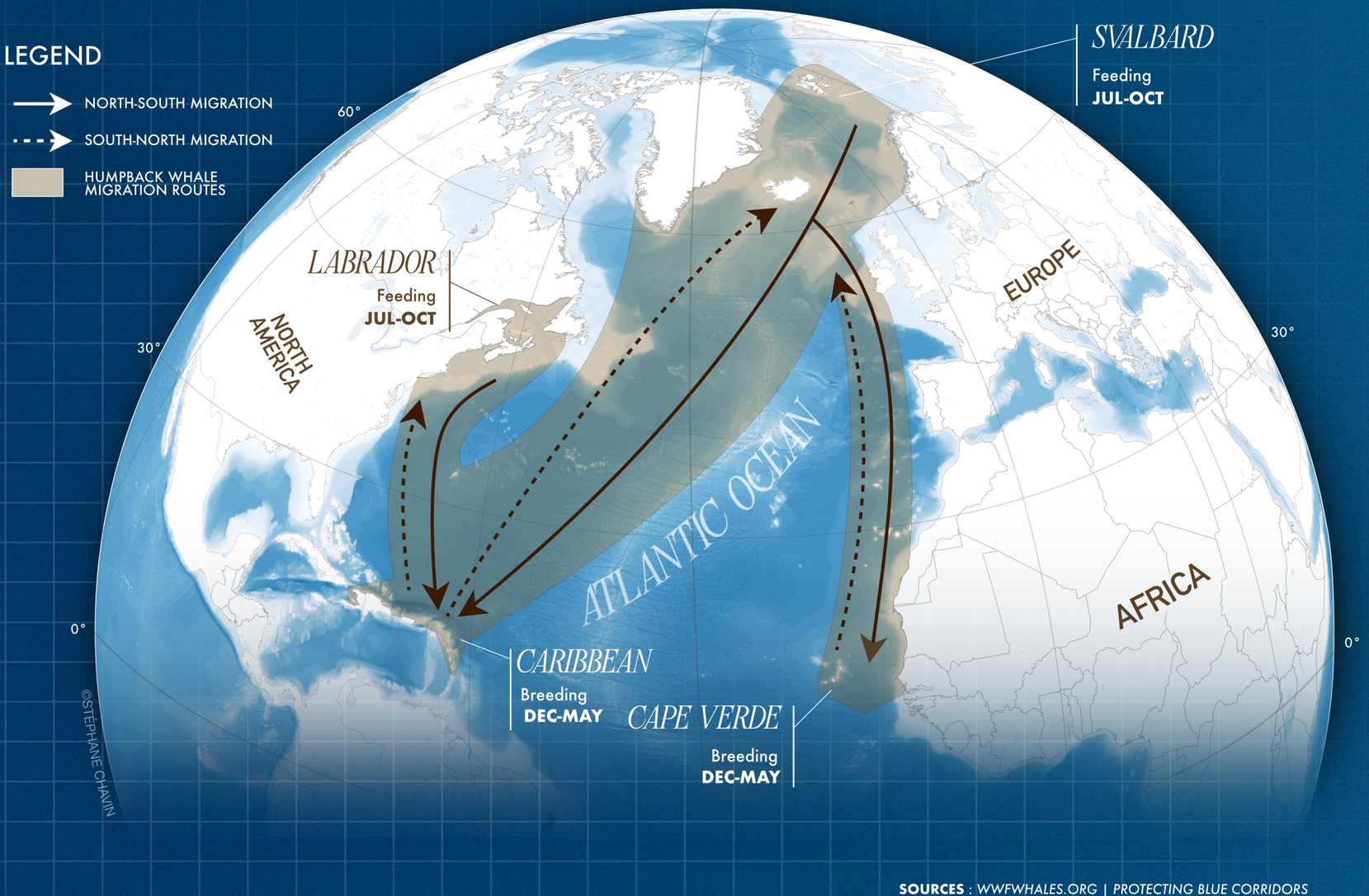
Megaptera novaeangliae



©Illustrator Frédérique Lucas

- *Use sound for communication and mating*
- *Mature male produces complex and organised sequences of vocalisation called song* [3]
- *Migrates from poles (feeding area) to the tropics (breeding area) to breeding*

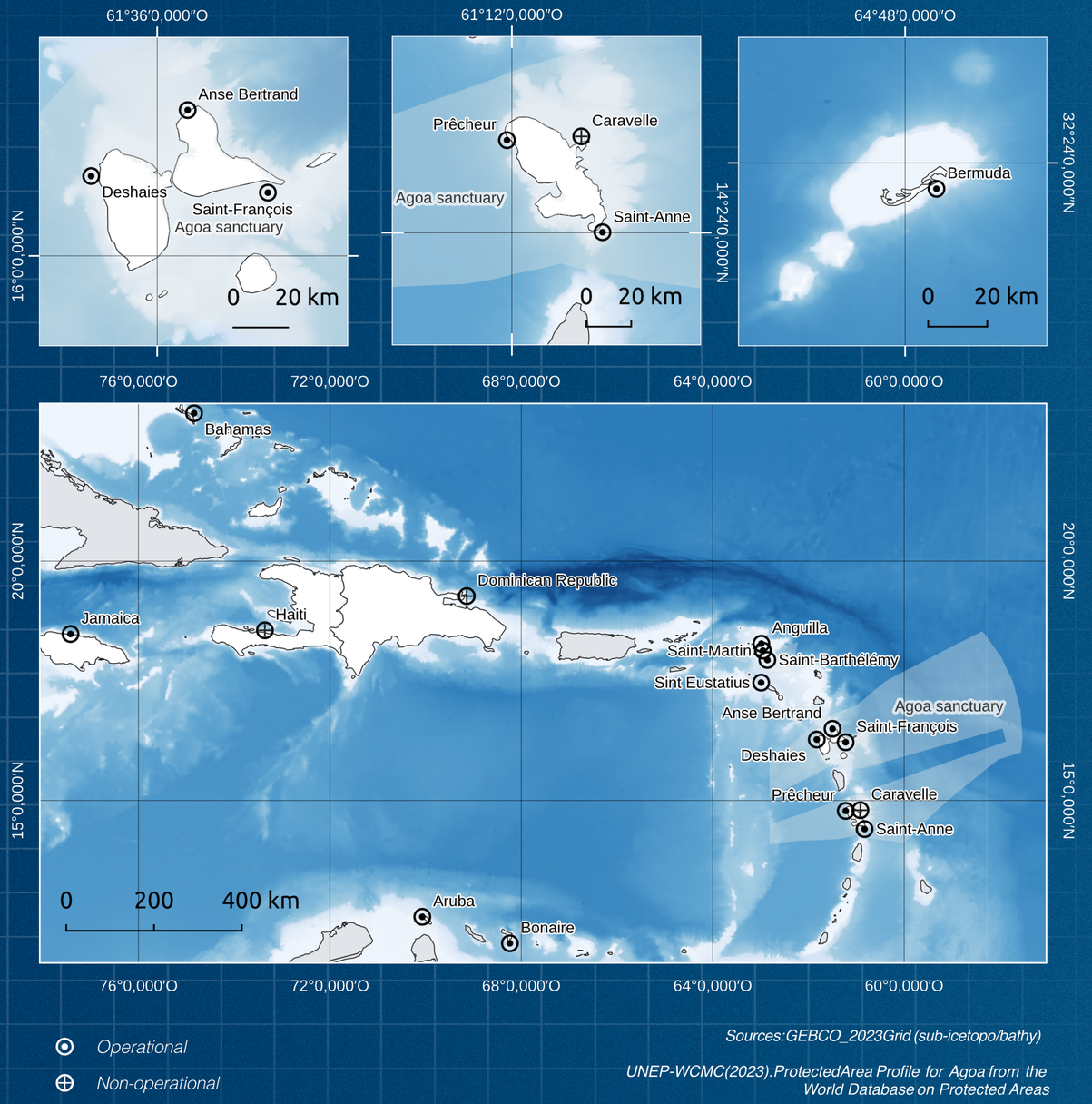
North Atlantic population : Migrates to the Caribbean for some and to Cape Verde for other between December to May.



SOURCES : *WWFWHALES.ORG | PROTECTING BLUE CORRIDORS*

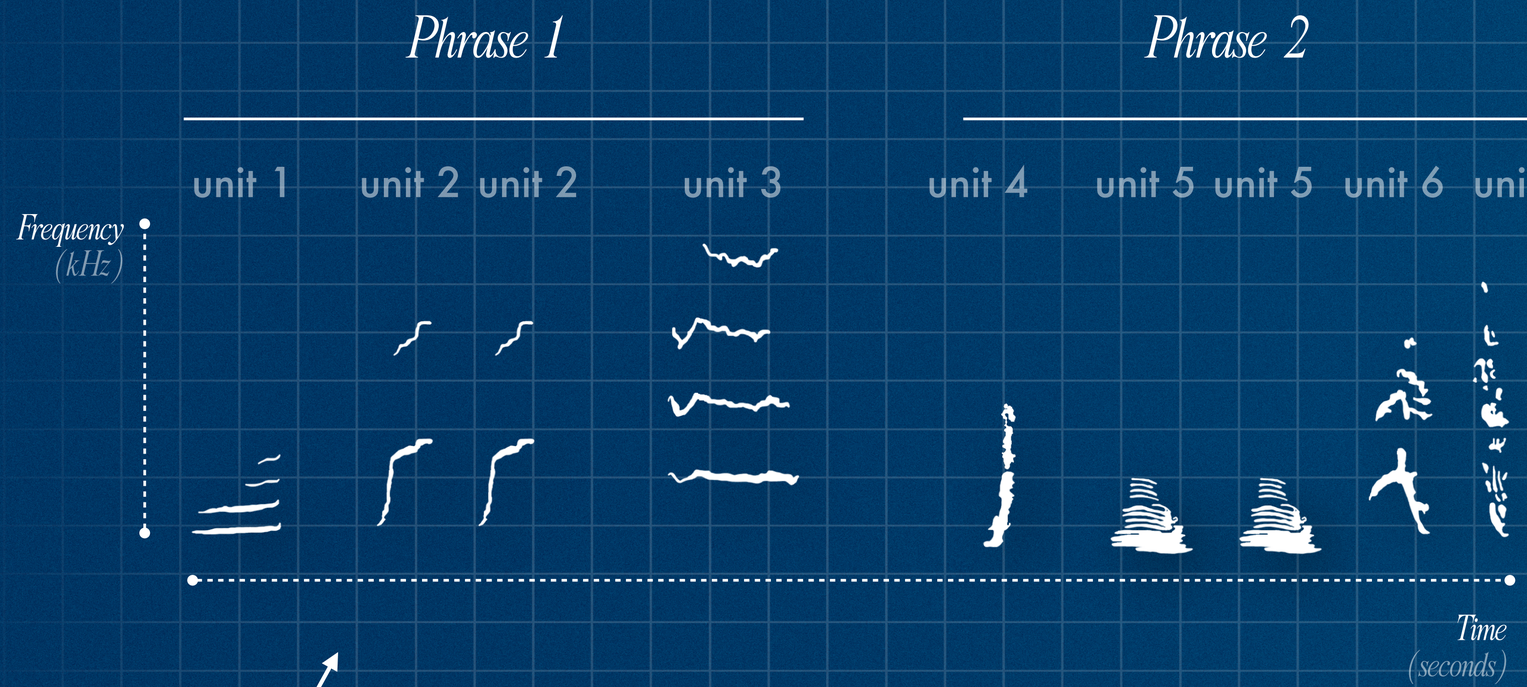
Map of the migration path for the North Atlantic population

- *Between December 2020 and the end of 2022, 17 Autonomous Recording Units (ARUs) placed across the Caribbean*
- *~20m depth, it records 1 minute every 6 minutes (duty cycle : 1 ON/5 OFF)*
- *~ 10 000 hours of recordings*



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HUMPBACK WHALE SONG [3]



a spectrogram

Unit : usually less than 3 seconds
Phrase : composed of 3 to 6 units
Theme : multiple phrases
Song : succession of themes (30 minutes)

Singing session : multiple hours

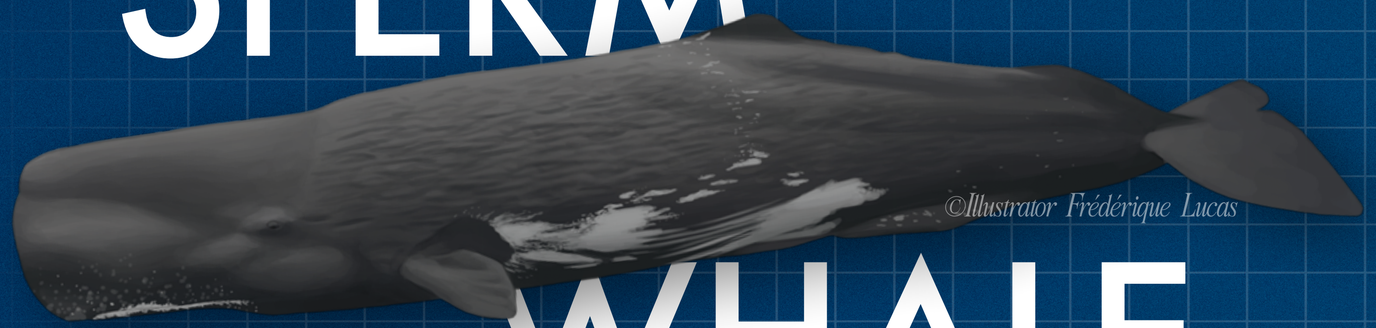
HUMPBACK WHALE SONG, *Guadeloupe*

©Stéphane Chavin

- *some context about*

SPERM WHALE

Physeter macrocephalus



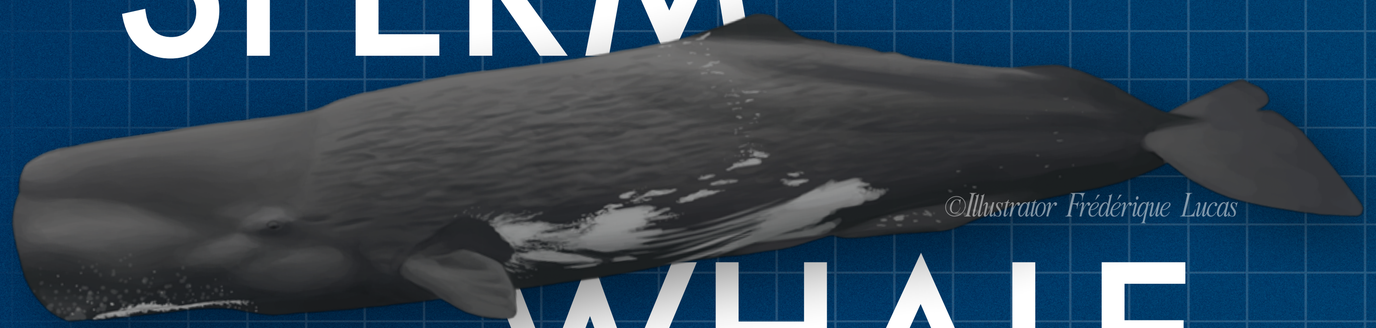
©Illustrator Frédérique Lucas

- *Produces various sound, for different purposes : echolocation clicks, codas, creak...*
- *Male migrates from poles to the tropics to breed, while female and calves stays in warmer and more stable waters* [4]
- *Population in the Mediterranean Sea*

- *some context about*

SPERM WHALE

Physeter macrocephalus

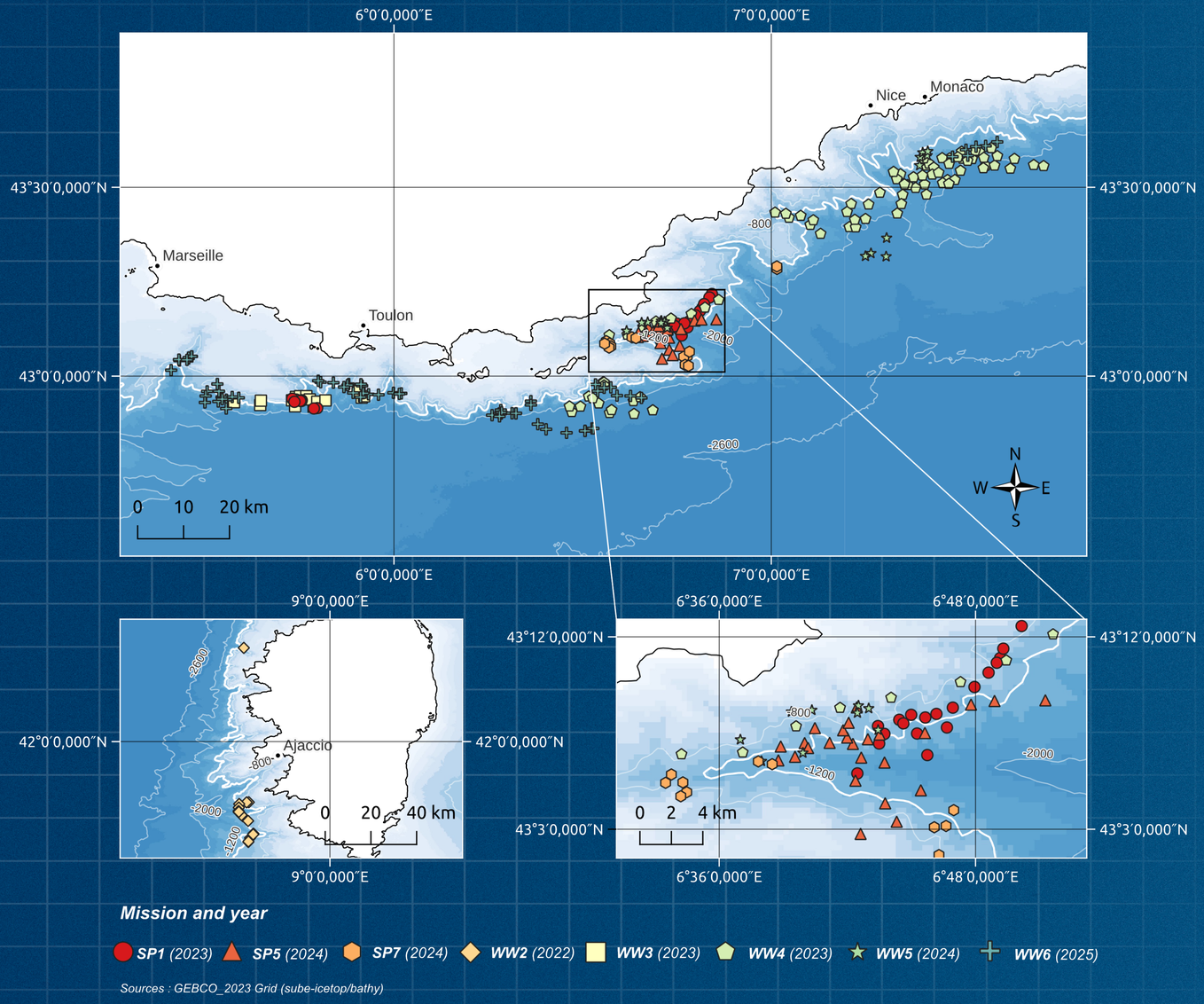


©Illustrator Frédérique Lucas

- *Produces various sound, for different purposes : echolocation clicks, codas, creak...*
- *Male migrates from poles to the tropics to breed, while female and calves stays in warmer and more stable waters* [4]
- *Population in the Mediterranean Sea*

  ~ 20 km from here (University of Toulon)

- *Protocol in 2 phases : 1. Searching for sperm whale using acoustic; 2. Recording with underwater acoustic array*
- *232 dives between 2022 and 2025 from 8 missions*
- *Almost all the observations are between Marseille and Monaco*



- *some context about*

BIRDS



©Bartels Science Illustrator Lauren Richelieu

- *Uses sound for different purpose : mating or defense (ex : song), communication (ex : call)* [5]
- *Some species are residents, while other are migrating : short-distance or long distance migration, mainly induced by endogenous annual rhythm* [6]

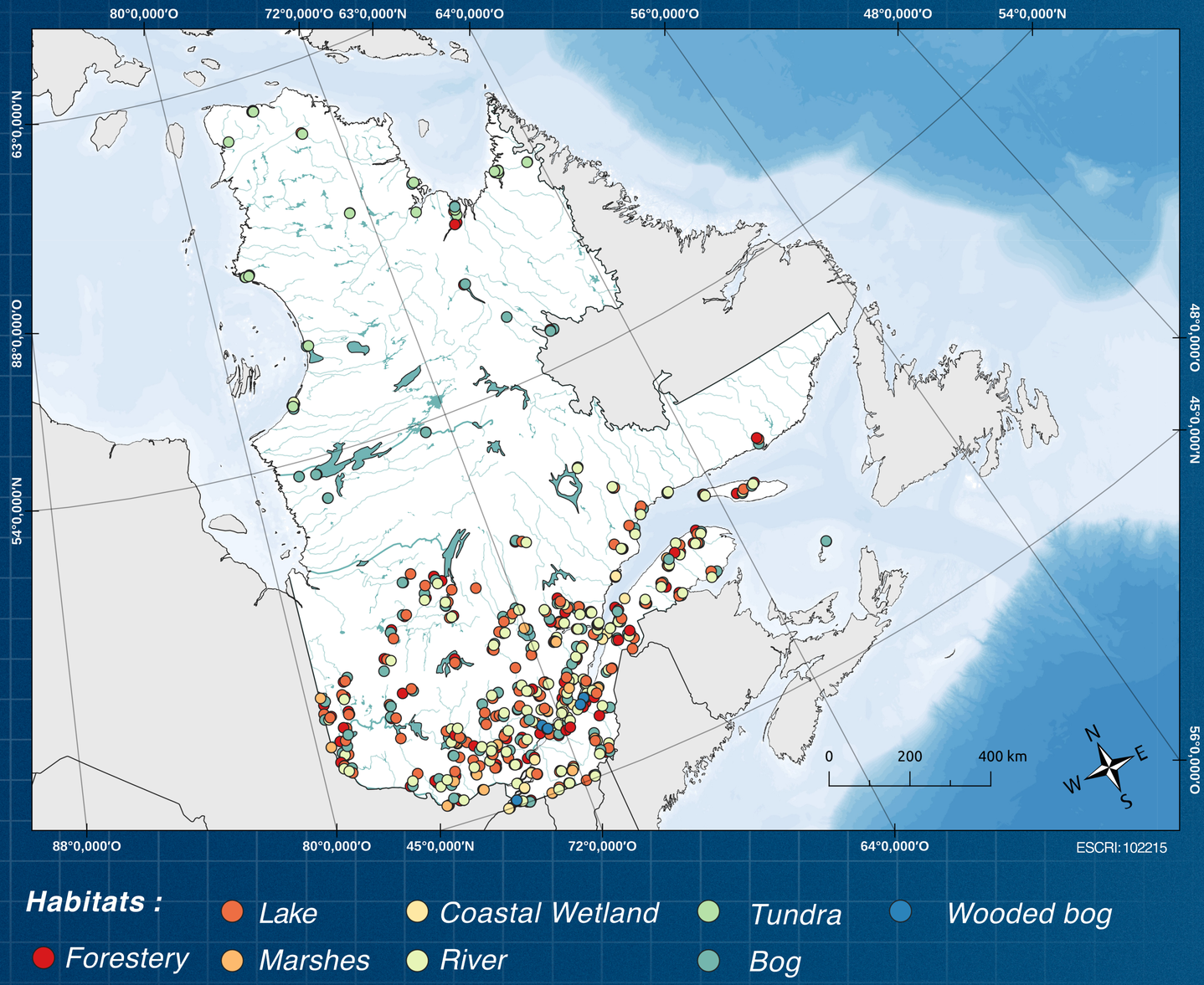
Spring migration generally occurs between March and June going through different flyway



SOURCES : BOREALCONSERVATION.ORG | NORTH AMERICA'S BIRD NUSERY

Map of the different flyways of birds in the Northern America continent [7]

- *Started in 2016 until now*
- *Over 200 different ARUs in various habitats*
- *Between 15-minutes and 1-hour recordings at specific time of the day*



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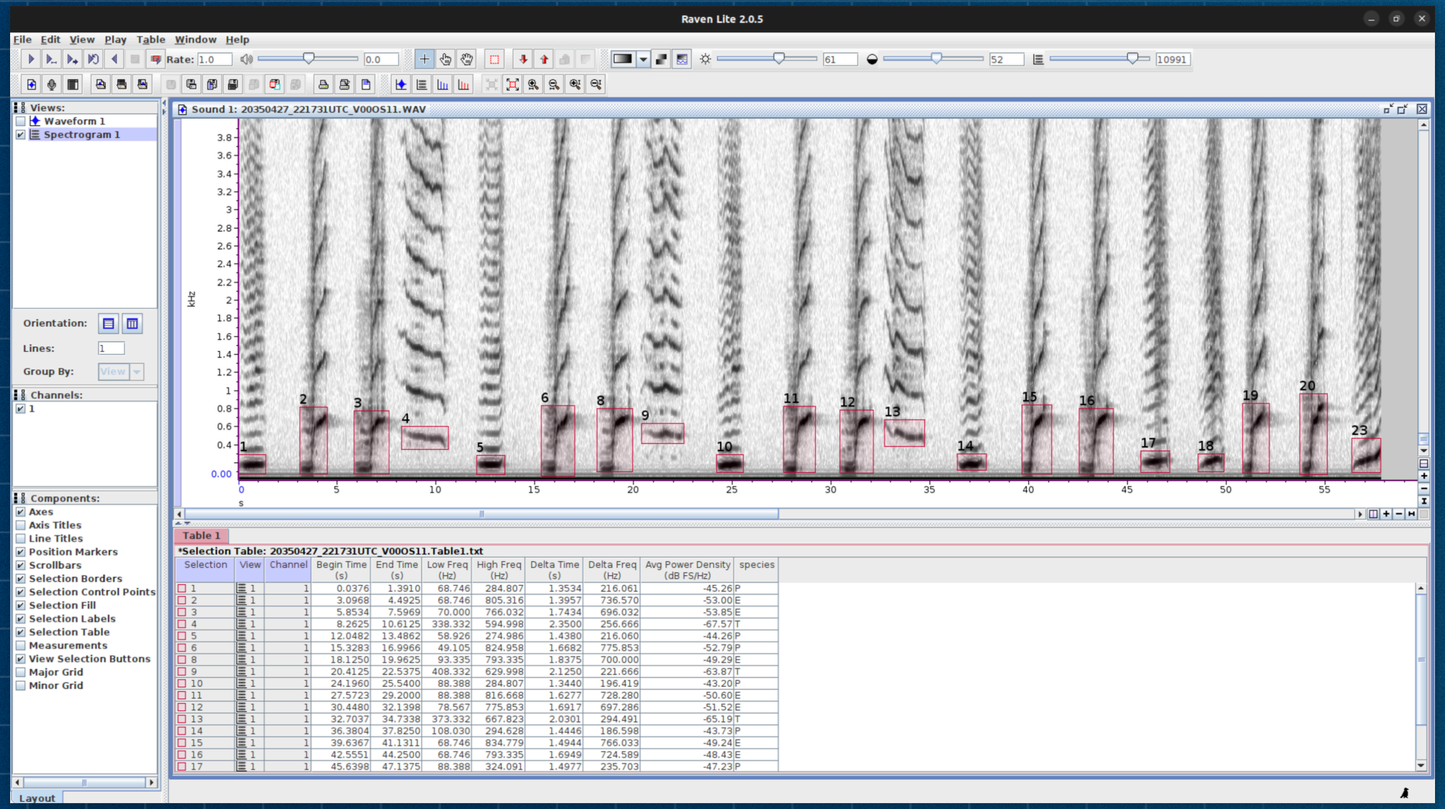
BIRD CHORUS

©Stephane Chavin, Indonesia

CENTRE int. d'INTELLIGENCE ARTIFICIELLE en ACOUSTIQUE NATURELLE

HOW CAN WE DETECT SPECIES IN A RECORDING ?

- *manually analyse with experts*

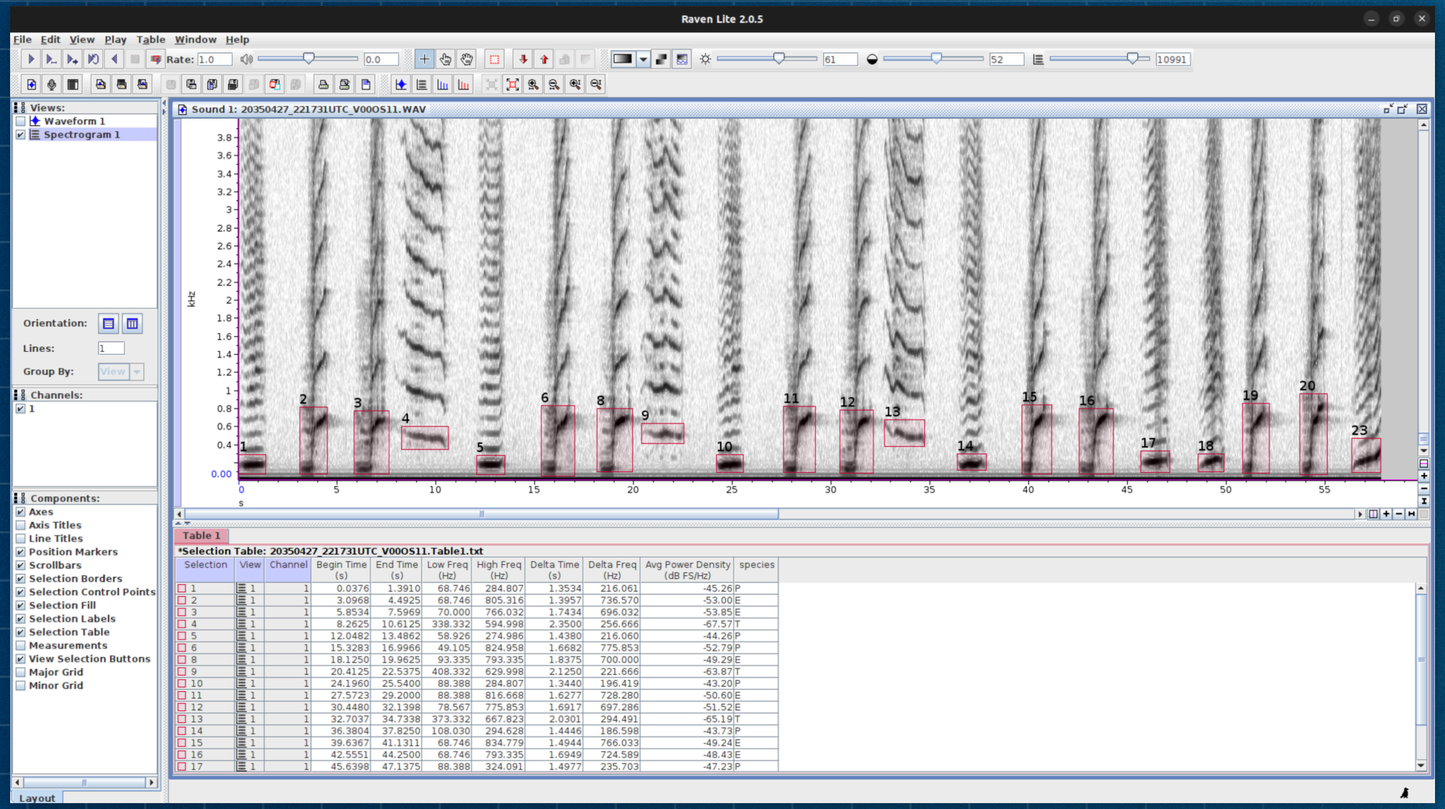


Selection	View	Channel	Begin Time (s)	End Time (s)	Low Freq (Hz)	High Freq (Hz)	Delta Time (s)	Delta Freq (Hz)	Avg Power Density (dB FS/Hz)	species
1	1	1	0.0376	1.3910	68.746	284.807	1.3534	216.061	-45.26	P
2	1	1	3.0968	4.4925	68.746	805.316	1.3957	736.570	-53.00	E
3	1	1	5.8534	7.5969	70.000	766.032	1.7434	696.032	-53.85	E
4	1	1	8.2625	10.6125	338.332	594.998	2.3500	256.666	-67.57	T
5	1	1	12.0482	13.4862	58.926	274.986	1.4380	216.060	-44.26	P
6	1	1	15.3283	16.9966	49.105	824.958	1.6682	775.853	-52.79	P
8	1	1	18.1250	19.9625	93.335	793.335	1.8375	700.000	-49.29	E
9	1	1	20.4125	22.5375	408.332	629.998	2.1250	221.666	-63.87	T
10	1	1	24.1960	25.5400	88.388	284.807	1.3440	196.419	-43.20	P
11	1	1	27.5723	29.2000	88.388	816.668	1.6277	728.280	-50.60	E
12	1	1	30.4480	32.1398	78.567	775.853	1.6917	697.286	-51.52	E
13	1	1	32.7037	34.7338	373.332	667.823	2.0301	294.491	-65.19	T
14	1	1	36.3804	37.8250	108.030	294.628	1.4446	186.598	-43.73	P
15	1	1	39.6367	41.1311	68.746	834.779	1.4944	766.033	-49.24	E
16	1	1	42.5551	44.2500	68.746	793.335	1.6949	724.589	-48.43	E
17	1	1	45.6398	47.1375	88.388	324.091	1.4977	235.703	-47.23	P

Raven annotation software

- *manually analyse with experts*

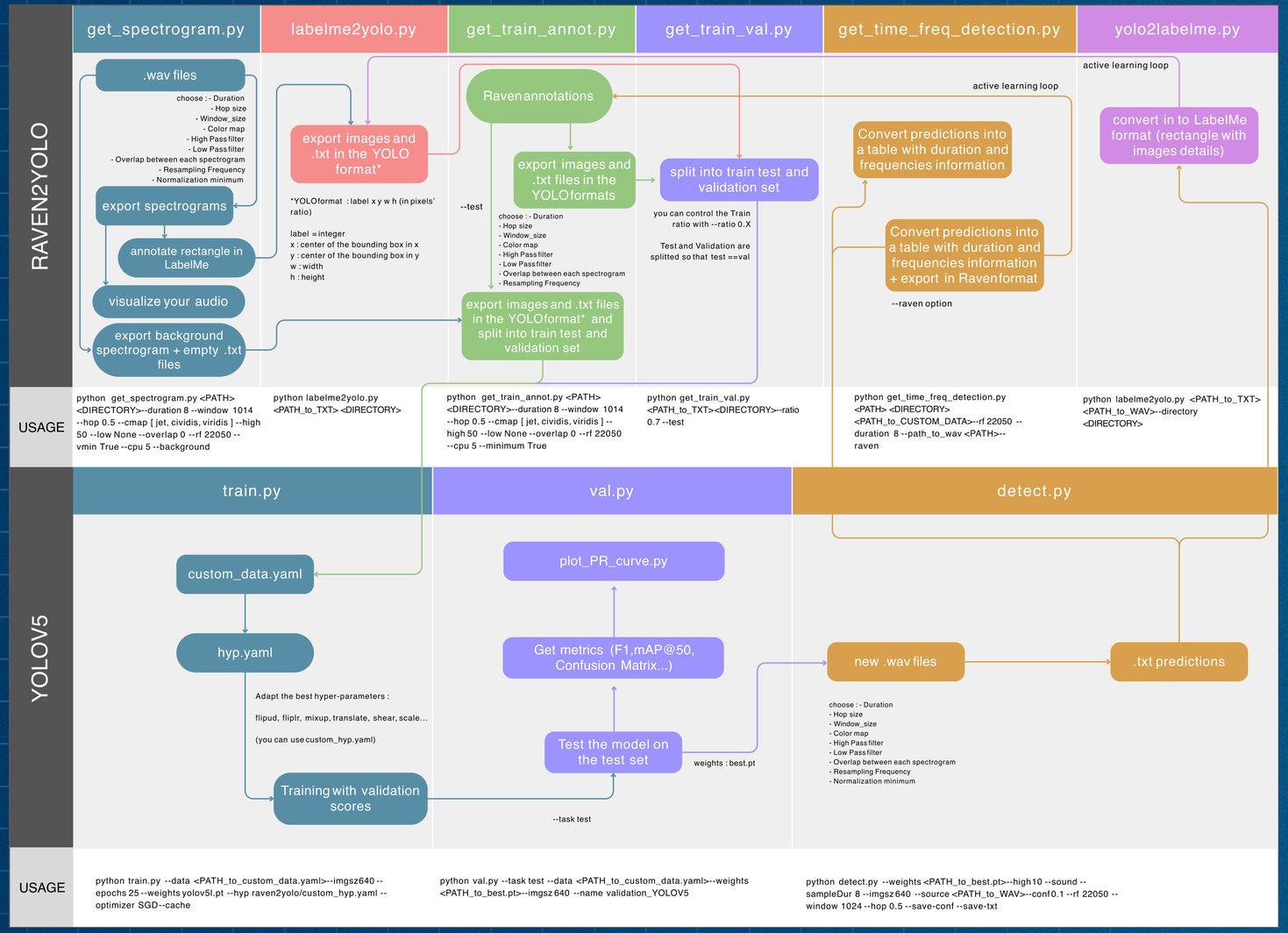
Québec = 341 000 files which would take approximately 20 years to listen entirely 24/7



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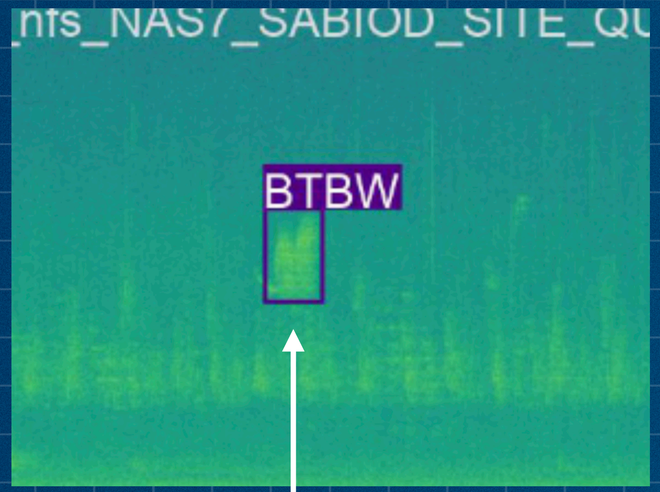
CENTRE int. d'INTELLIGENCE ARTIFICIELLE en ACOUSTIQUE NATURELLE

- *A full pipeline to adapt Raven or LabelMe annotations into a format to train a YOLOv5 model* [8]
- *YOLO (You Only Look Once) is an deep learning model that is used for object detection and requires box annotations*

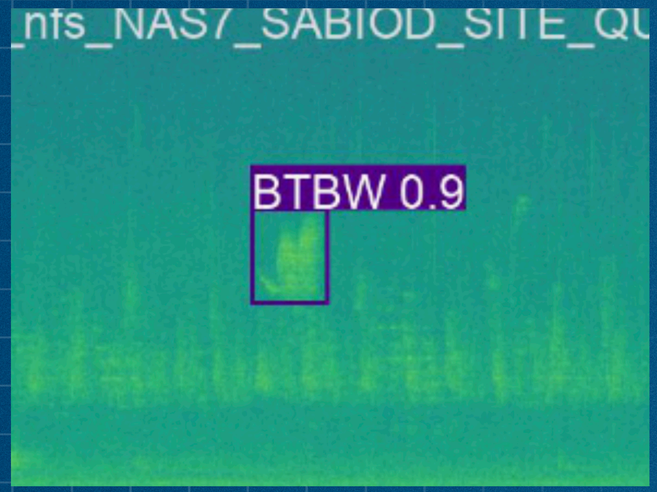


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INPUT



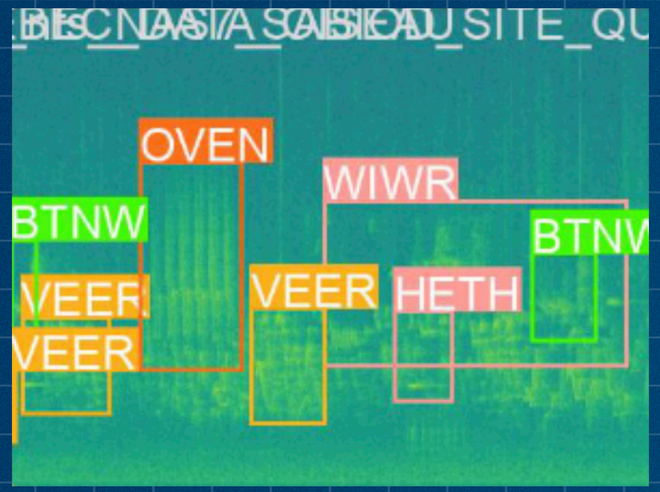
OUTPUT



Black-throated blue warbler

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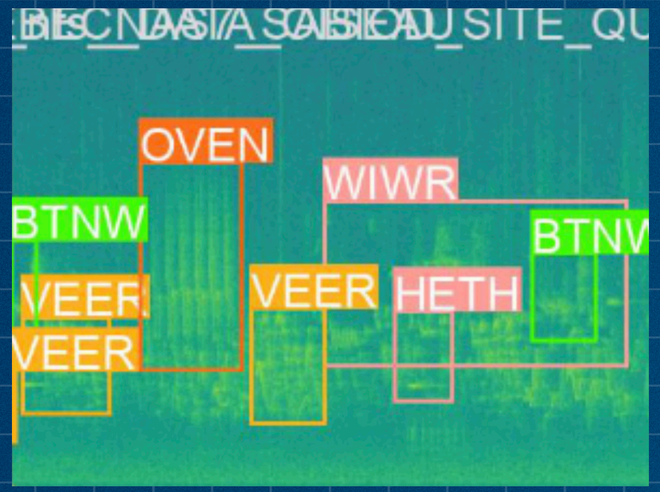


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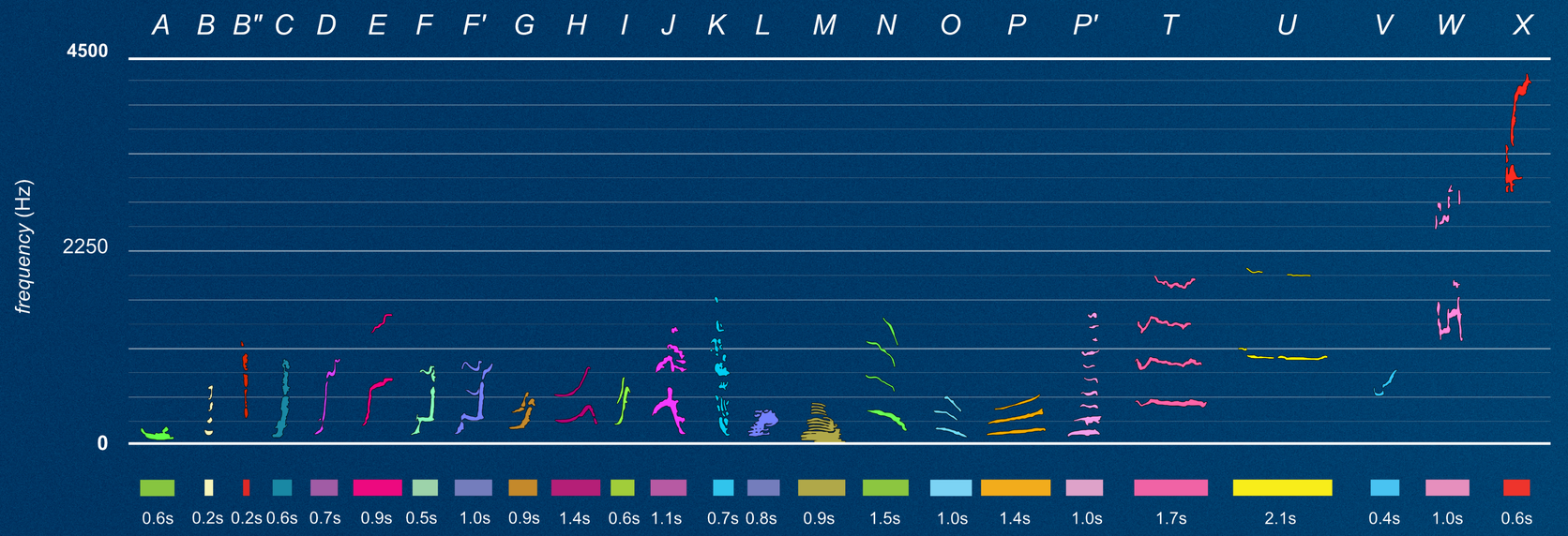
INPUT



OUTPUT



= Québec dataset's can be analysed in 45 days



Vocal repertoire for the North Atlantic population of Humpback whale between 2020 and 2022

1. VOCAL REPERTOIRE

- *23 units for humpback whale*
- *27 bird species*

2. ANNOTATION

- *Raven bounding boxes*

3. ACTIVE LEARNING LOOPS

- *Increase the training set with more and various examples*

4. COMPARE

- *Evaluate the model using different metrics and compare to other architectures*

MODELS EVALUATION

$$mAP = \frac{1}{N} \sum_{i=1}^{n} AP_i$$

$$AP = \sum_{i=1}^{n-1} (r_{i+1} - r_i) \times p_{interp}(r_{i+1})$$

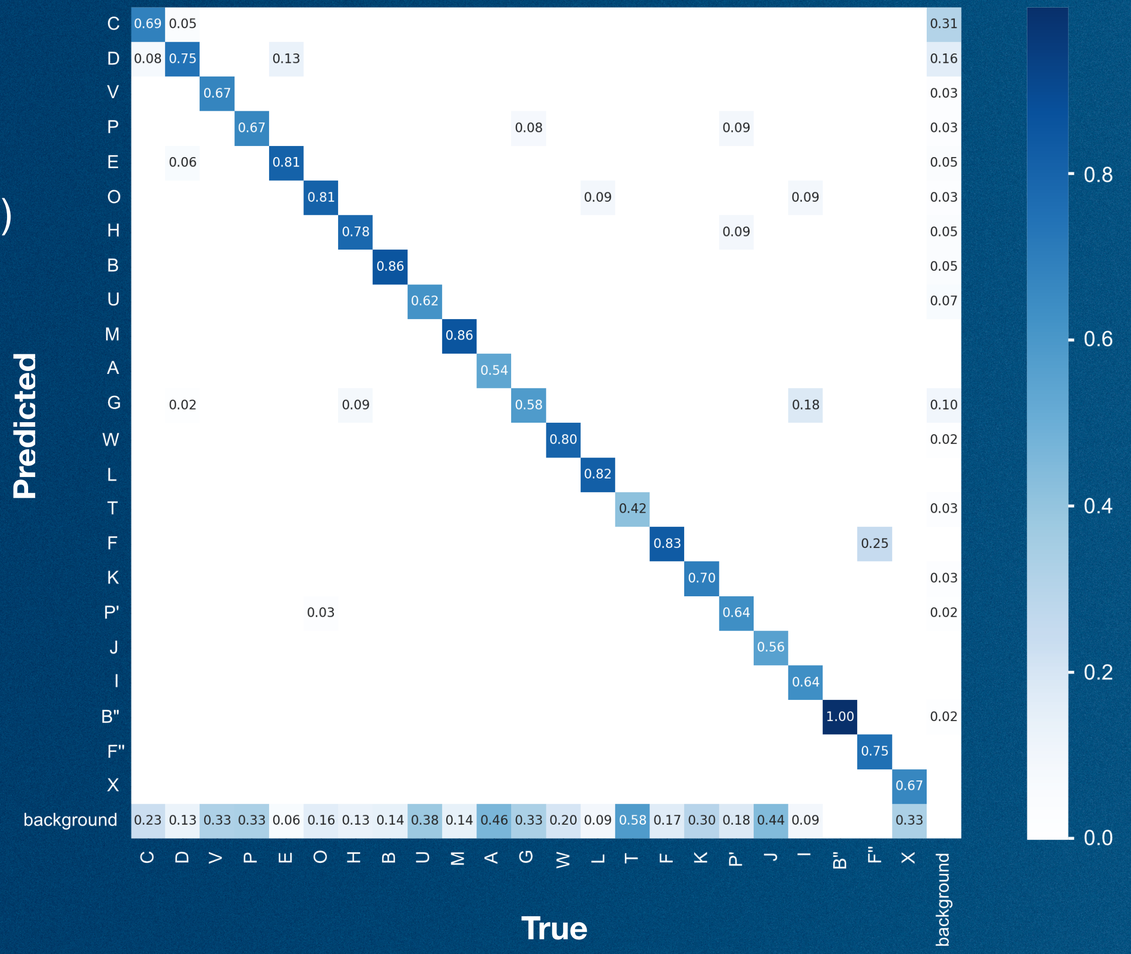
Humpback whale model :

- *mAP@50 of 74% for 23 units*
- *Low confusion between units*

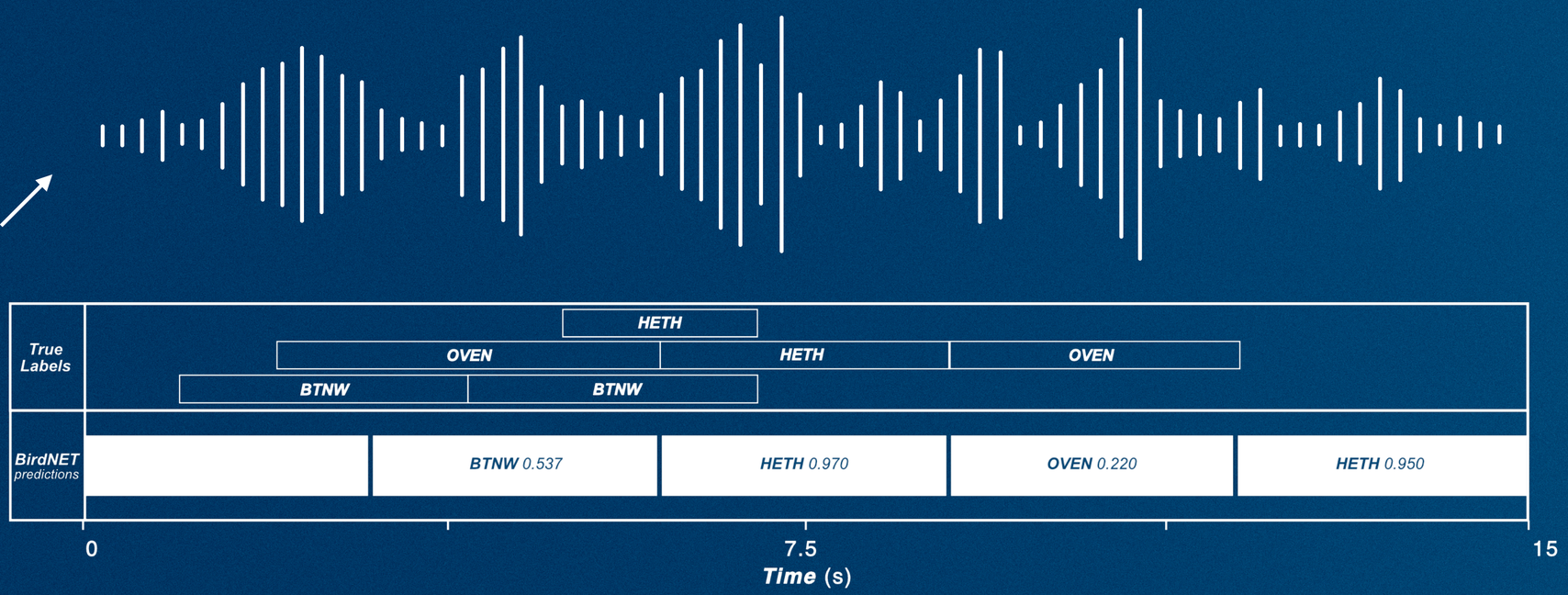
Bird model :

- *mAP@50 of 82% for 27 species*
- *Better scores than BirdNET, even in high chorus scenarios*

Humpback whale confusion matrix



15 seconds audio signal

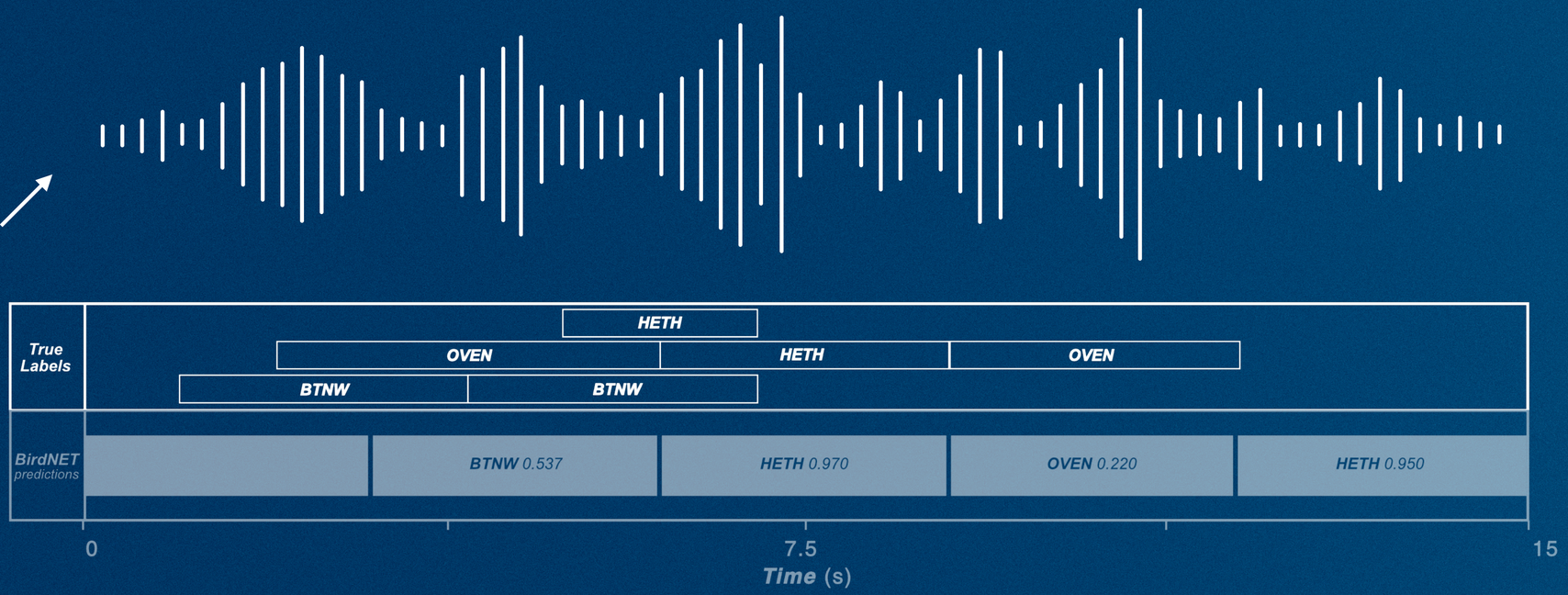


TRUE LABELS / EXPERTS

Start time, end time and species name

Highly precise, but time consuming

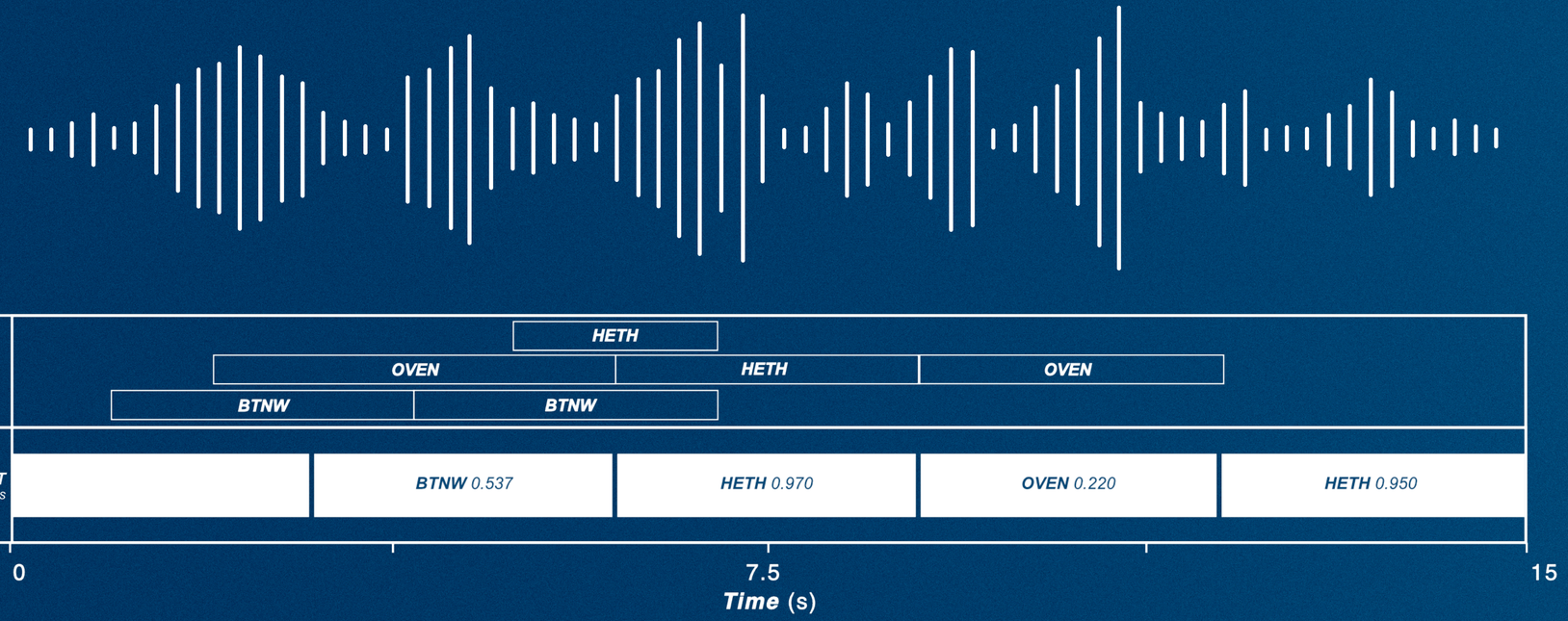
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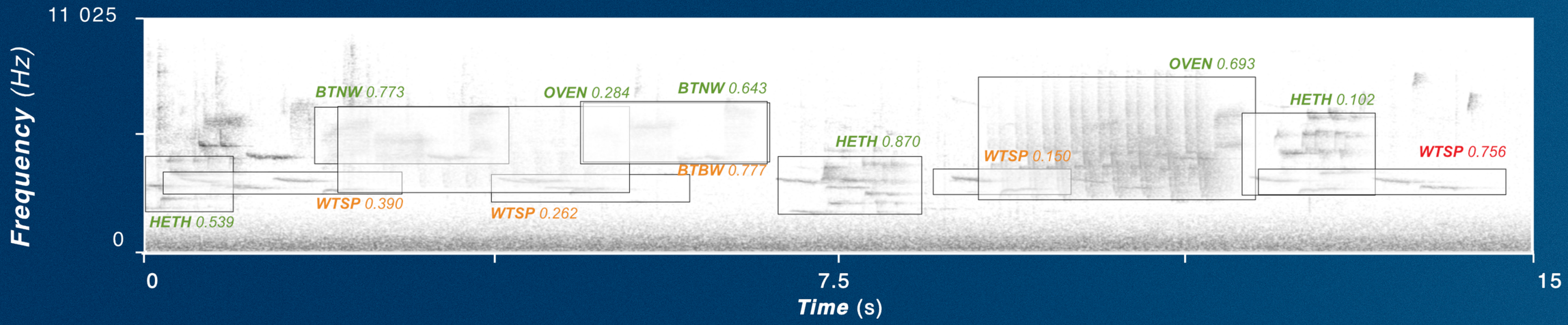
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Highly precise, but time consuming

BirdNET [9]

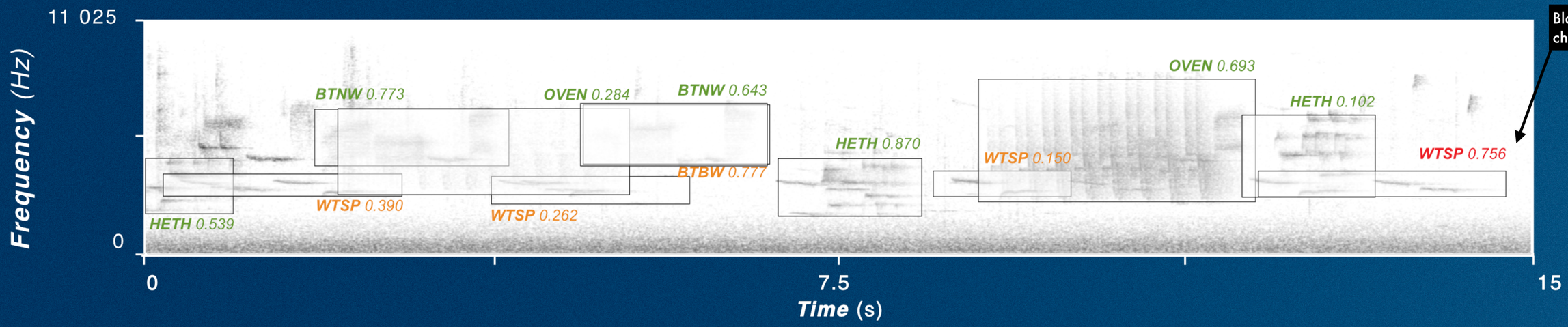
Confidence every 3 seconds associated to each species (over 6000 species)
Quick but less informations and less precision

OUR MODEL [10]



Begin Time (s)	End Time (s)	Duration (s)	Minimum Frequency (Hz)	Maximum Frequency (Hz)	Confidence	Species
0.00	0.96	0.96	1929	4524	0.539	**HETH** (Hermit trush)
0.21	2.79	2.58	2779	3812	0.390	**WTSP** (White-throated sparrow)
1.82	3.93	2.11	4203	6844	0.773	**BTNW** (Black-throated Green Warbler)
2.08	5.22	3.14	2871	6890	0.284	**WTSP** (White-throated sparrow)
…						

OUR MODEL [10]

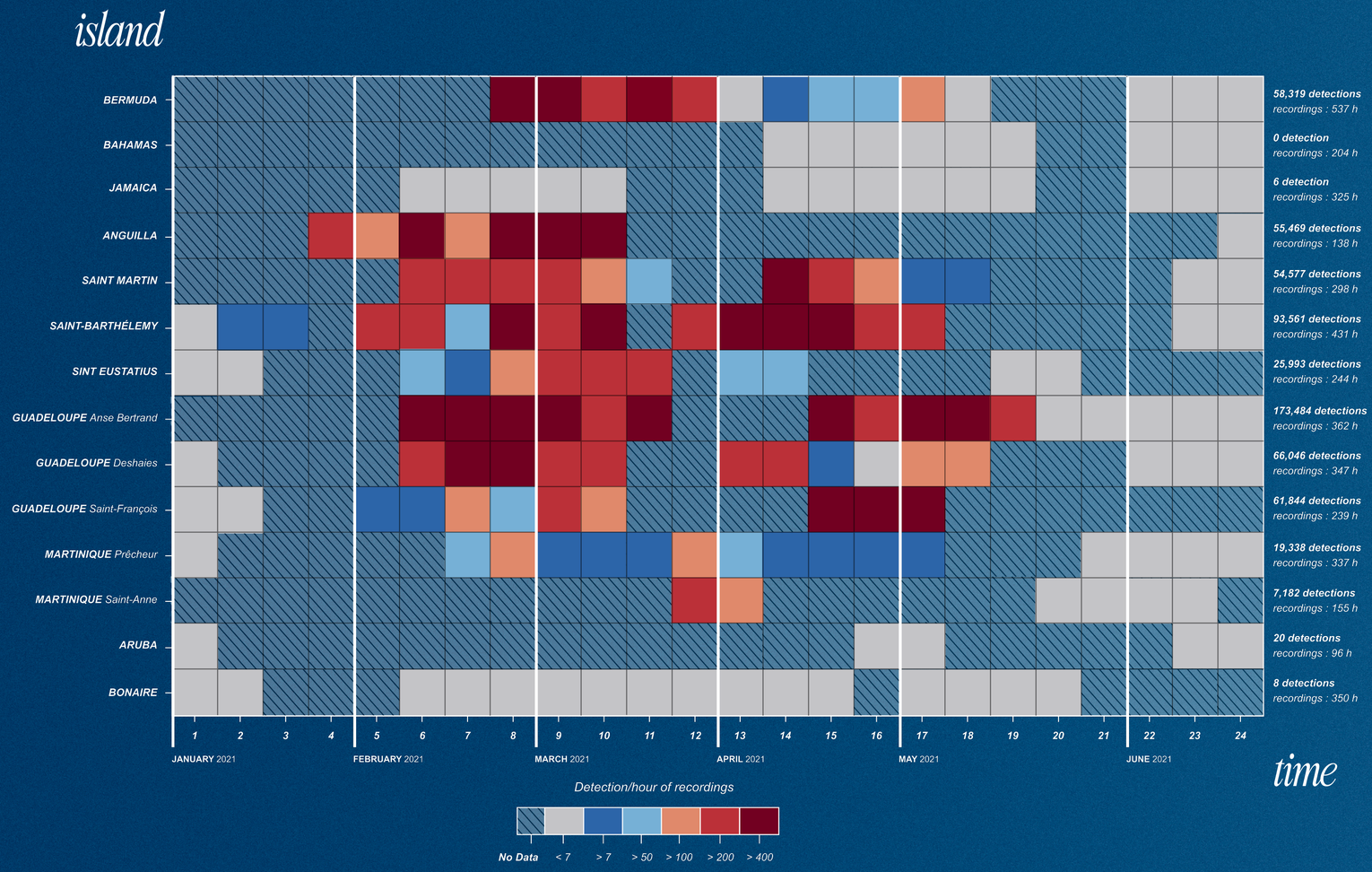


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…						

+ 300 000 detections between 2021 and 2022 in 14 stations [11]

FINDINGS :

- Verified the seasonal migration period
- The repertoire usage varies during the breeding season, with harmonisation and variations

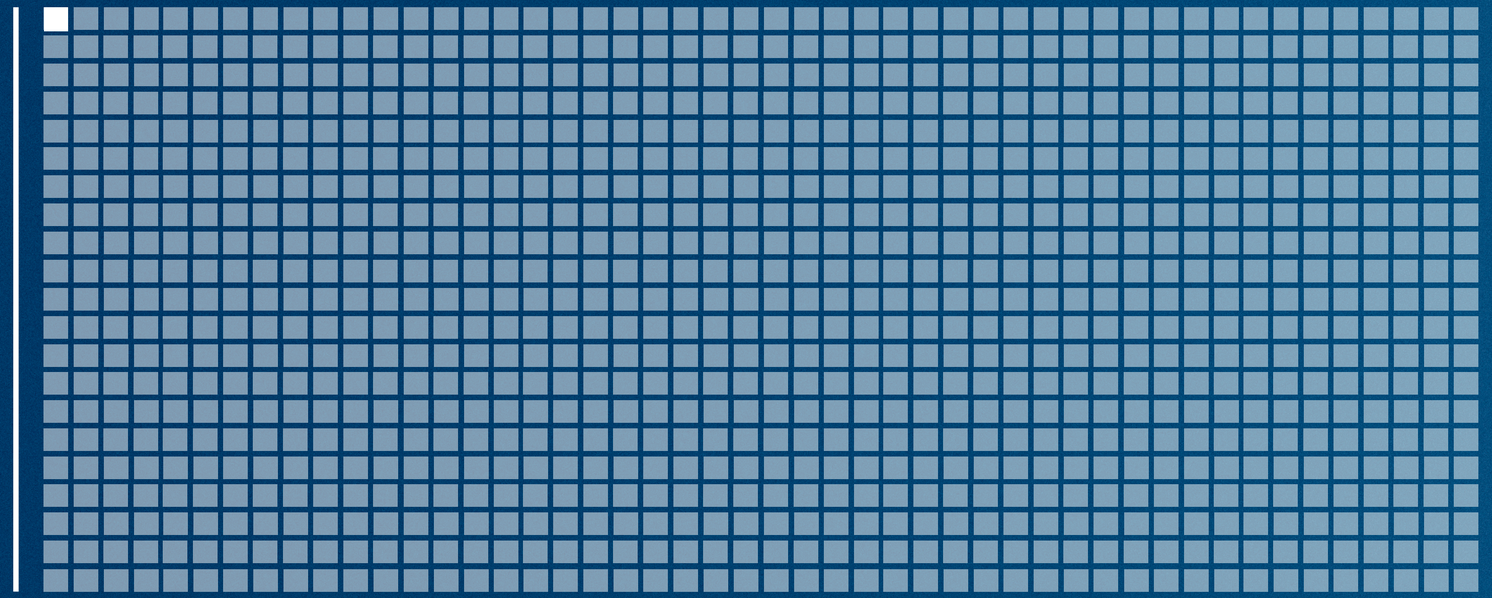


CENTRE int. d'INTELLIGENCE ARTIFICIELLE en ACOUSTIQUE NATURELLE

- *29 795 annotations (22.5 hours of recordings)*
- *~22 million detections from 2016 to 2025 in 16 different regions of Québec*

29 795 annotations ⟶ ■

~22 million detections



HOW TO ANALYSE THESE RESULTS TO UNDERSTAND SPECIES PREFERENCES ?

SPECIES DISTRIBUTION MODELING (SDM)

MAXENT MODELS [12]

- *Presence only models*
- *Generate background points*
- *Use averaged parameters*

↓

SPERM WHALE

GAM MODELS [13]

- *Presence-absence models*
- *Can take the environmental layers with each corresponding informations*

↓

HUMPBACK WHALE & BIRDS

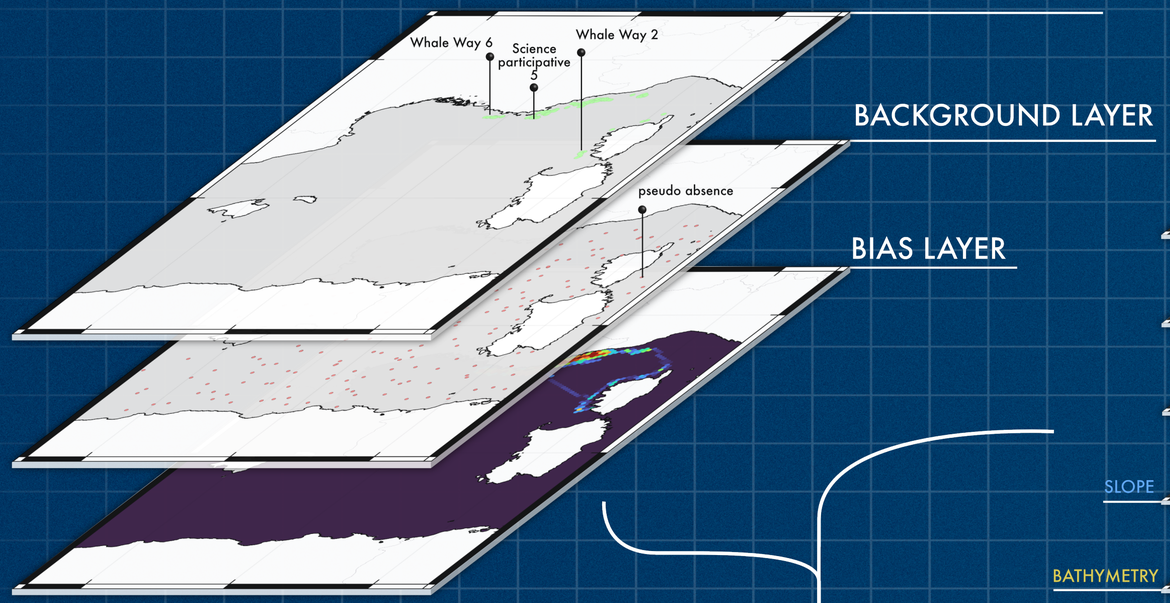
MAXENT MODEL

SAMPLES

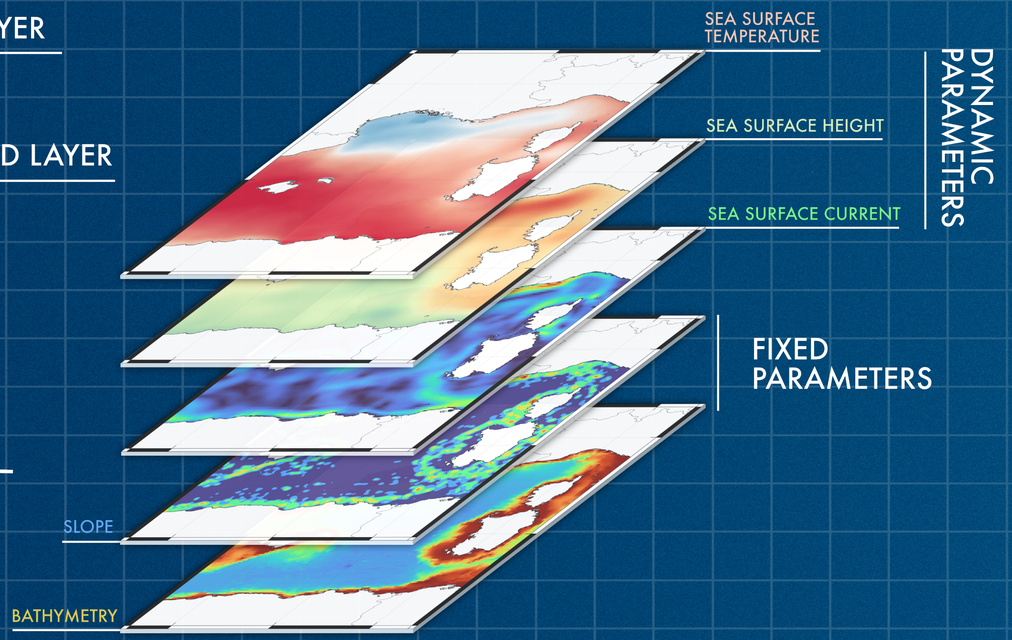
PRESENCE LAYER

BACKGROUND LAYER

BIAS LAYER

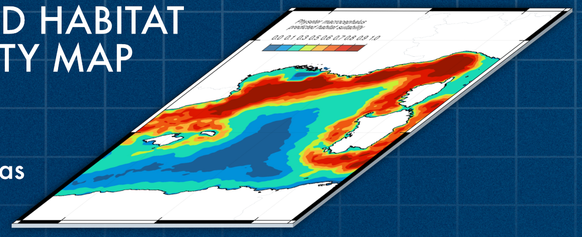


VARIABLES



MaxENT optimisation

PREDICTED HABITAT SUITABILITY MAP



+ value of the Area Under the Curve (AUC) True positive rate as a function of False positive rate

1. Only fixed parameters

2. Fixed and dynamic parameters

3. Optimising the results by using only the best parameters

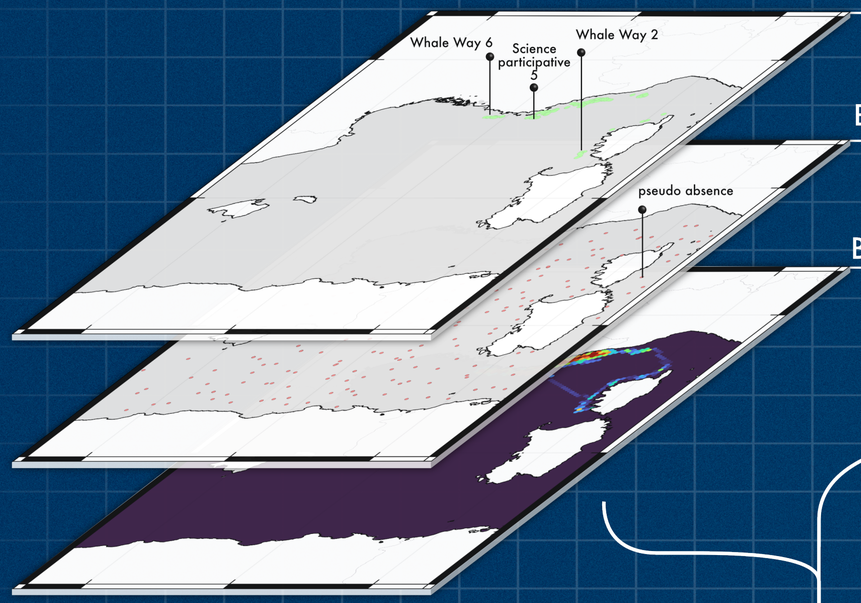
MAXENT MODEL

SAMPLES

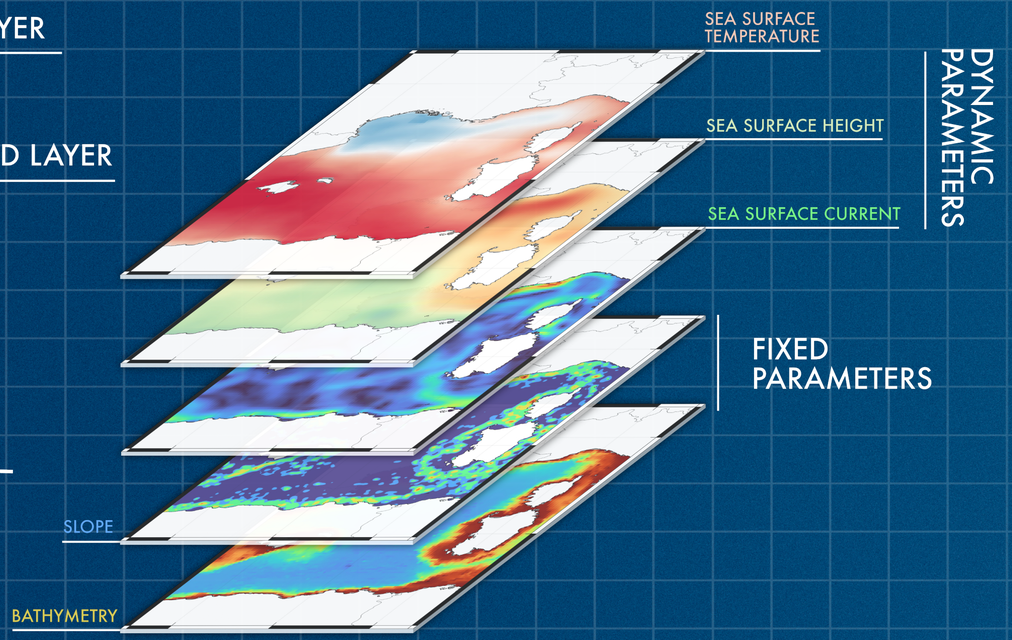
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BACKGROUND LAYER

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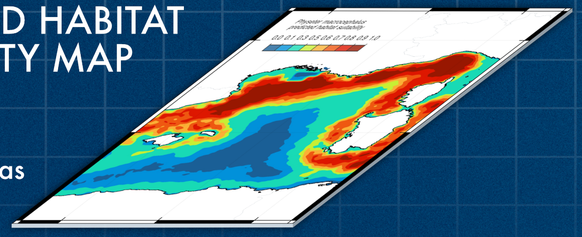


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CENTRE int. d'INTELLIGENCE ARTIFICIELLE EN ACOUSTIQUE NATURELLE

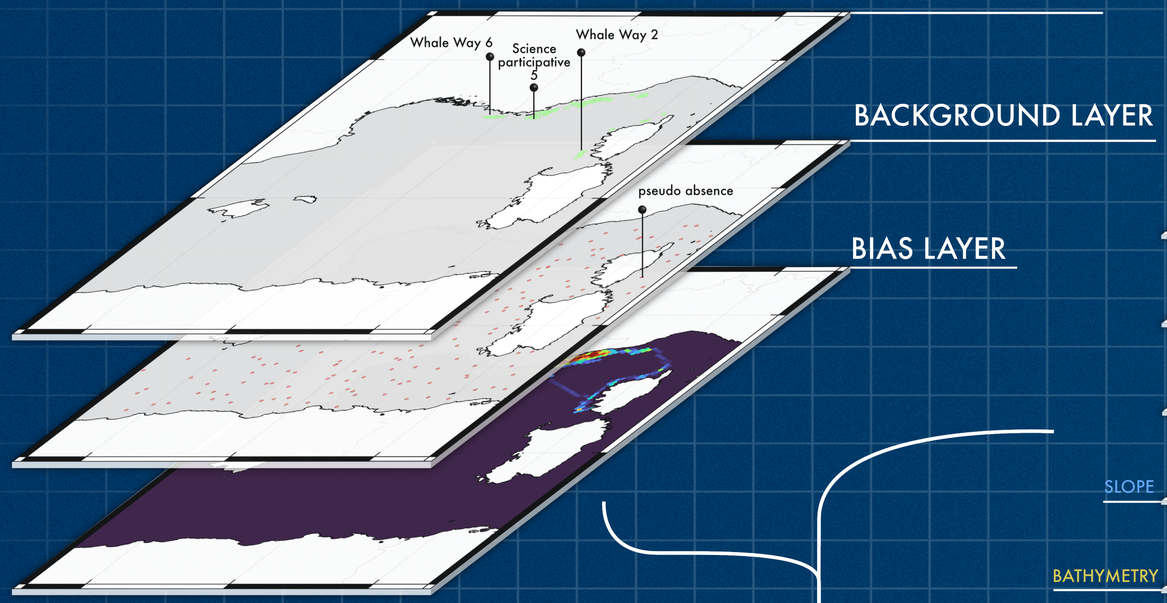
MAXENT MODEL

SAMPLES

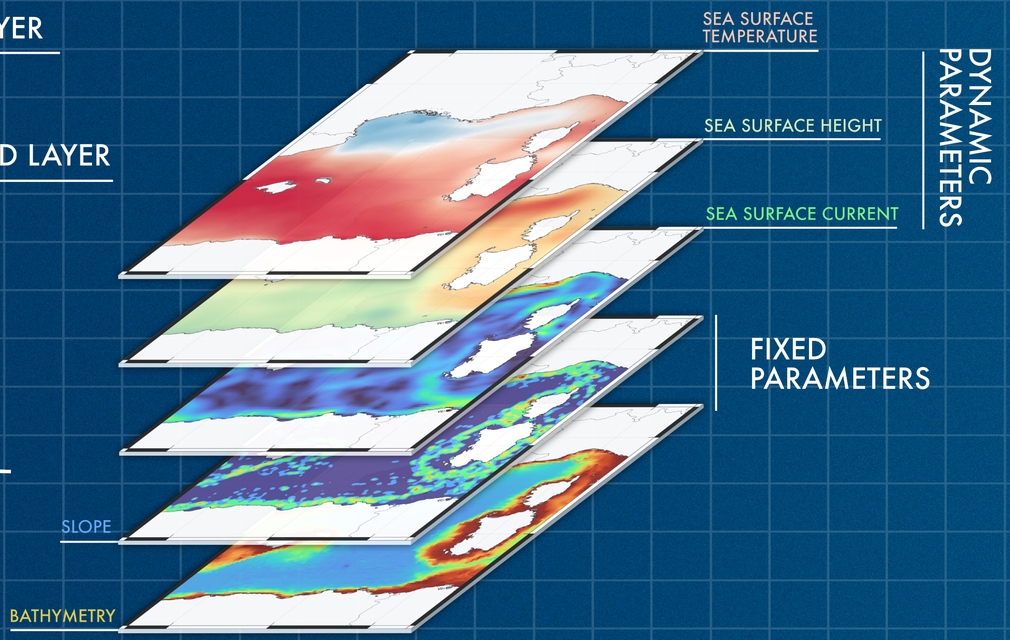
PRESENCE LAYER

BACKGROUND LAYER

BIAS LAYER

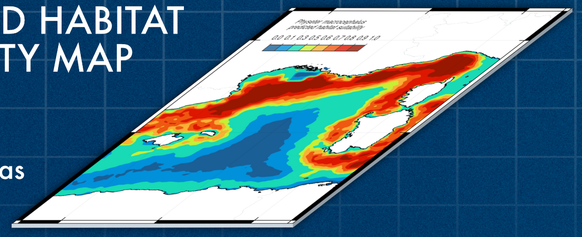


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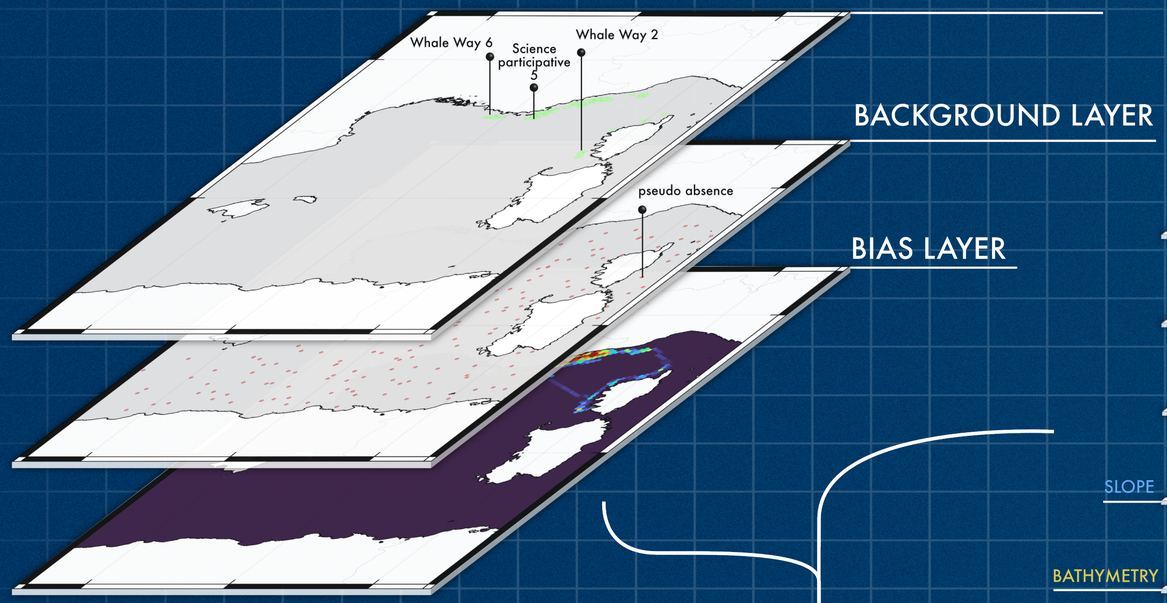
MAXENT MODEL

SAMPLES

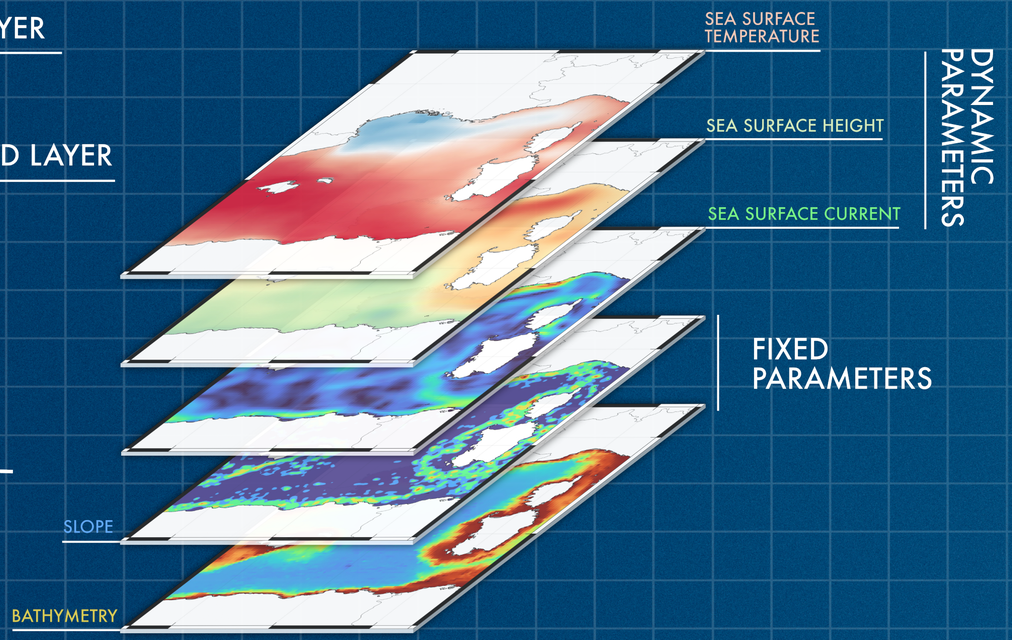
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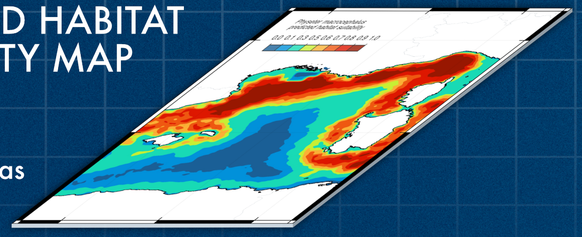


VARIABLES



MaxENT optimisation

PREDICTED HABITAT SUITABILITY MAP



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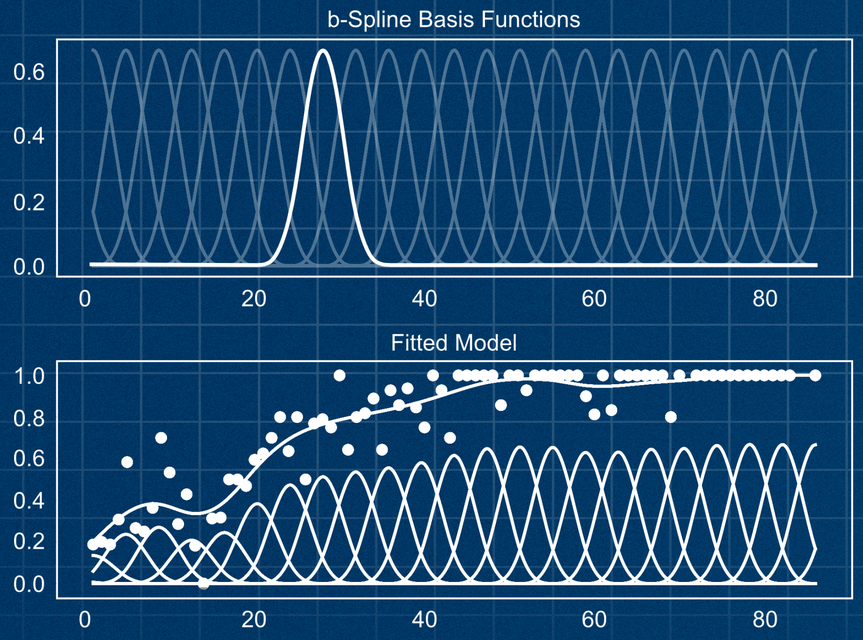
3. Optimising the results by using only the best parameters

CENTRE int. d'INTELLIGENCE ARTIFICIELLE EN ACOUSTIQUE NATURELLE

GAMs MODEL

parameters in the model

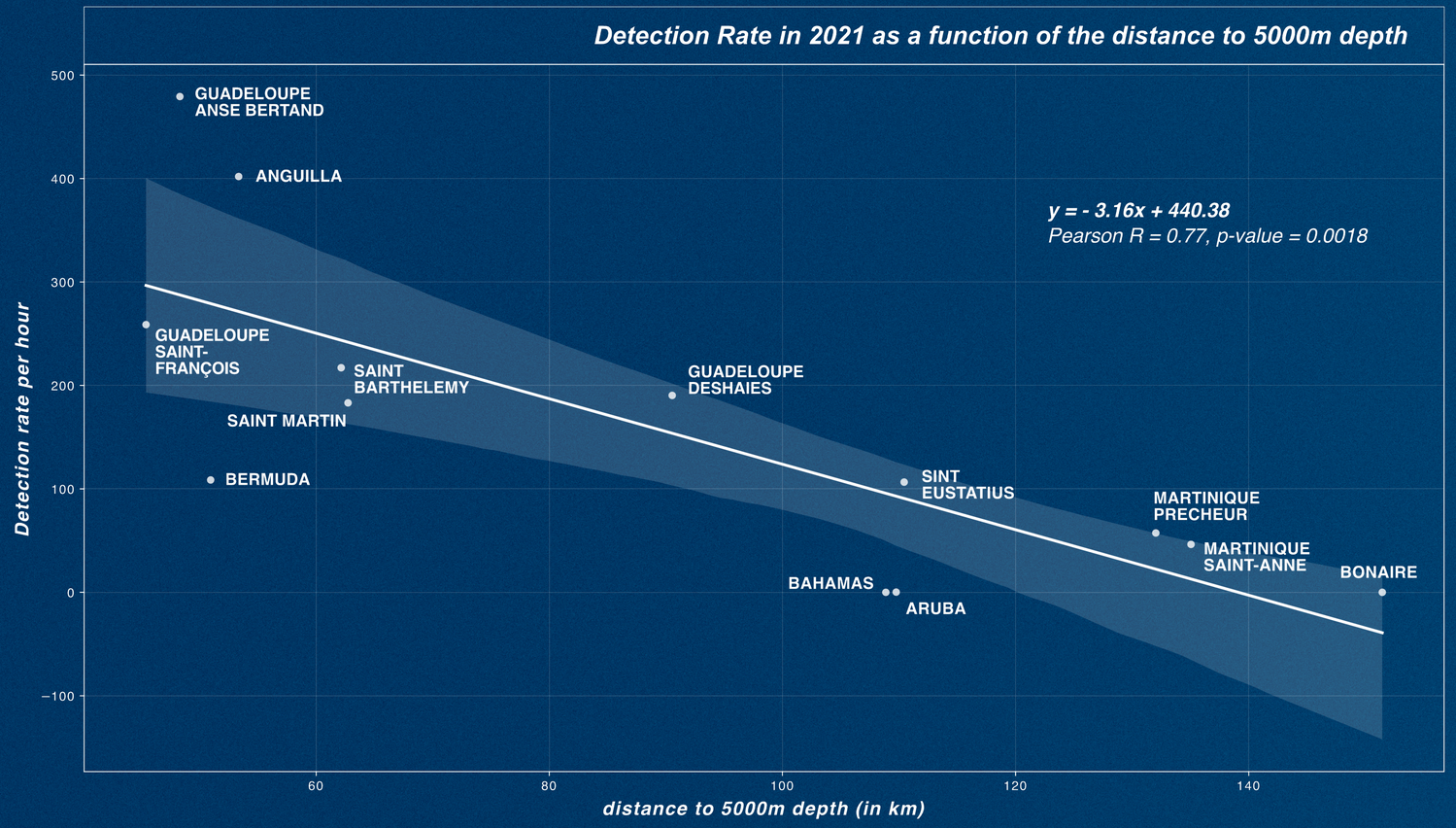
Detection rate (detection/hour or recording)	Temperature	Salinity	Chlorophyll concentration	Week number	Date
150	25.2	36.0	0.08	12	2021-03-24
220	25.6	36.5	0.09	13	2021-04-01
33	27.6	34.5	0.12	2	2021-01-12
75	24.5	35.0	0.16	27	2021-07-08



Optimise all splines to fit to the input datas

= result with a R^2 value for the optimised curve

RESULTS : Humpback whale

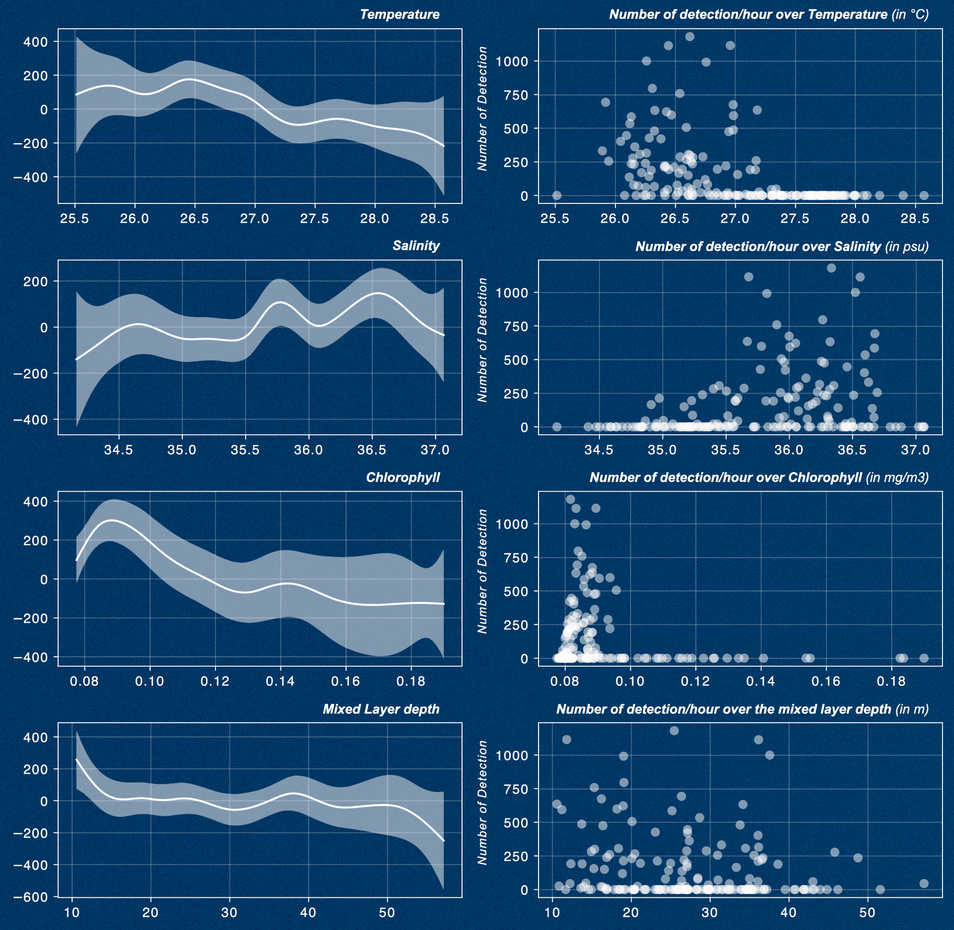


1. FIXED PARAMETER

Significant negative correlation between the detection rate (associated to singing behavior) and the distance of the island to the 5000m depth

-> closer to the Antilles arc = higher detection rate

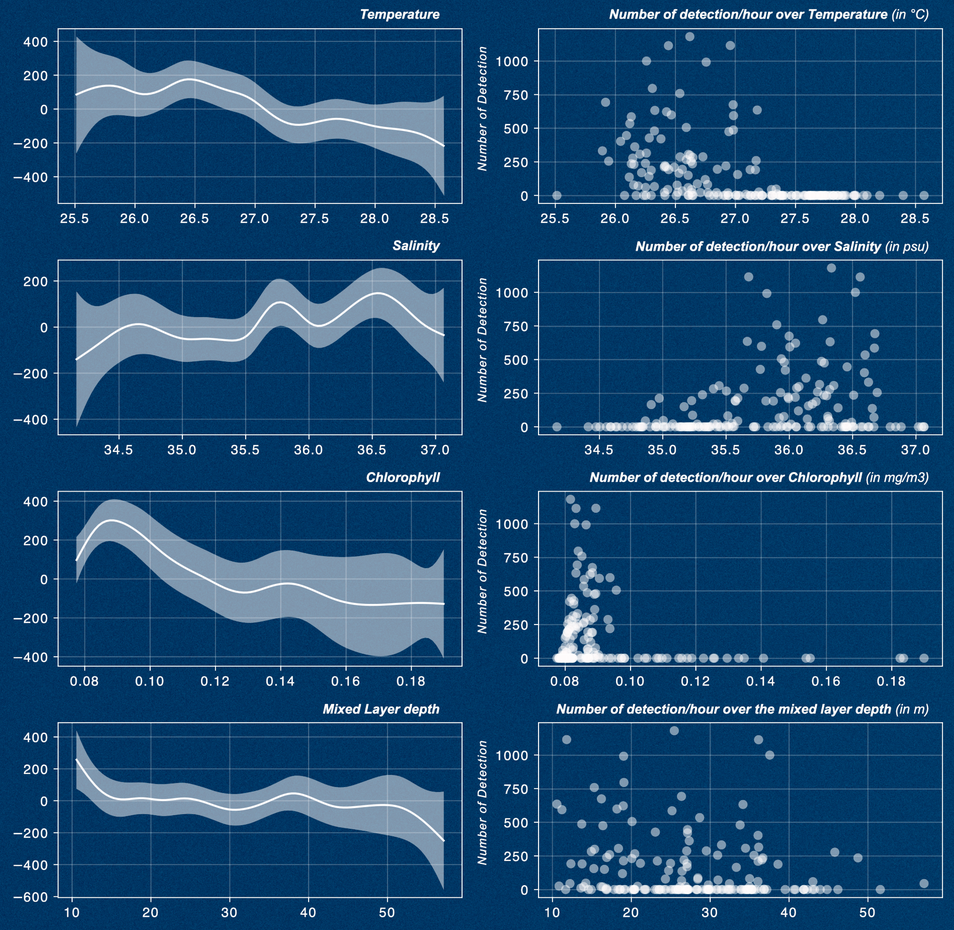
RESULTS : Humpback whale



2. VARIABLE PARAMETER

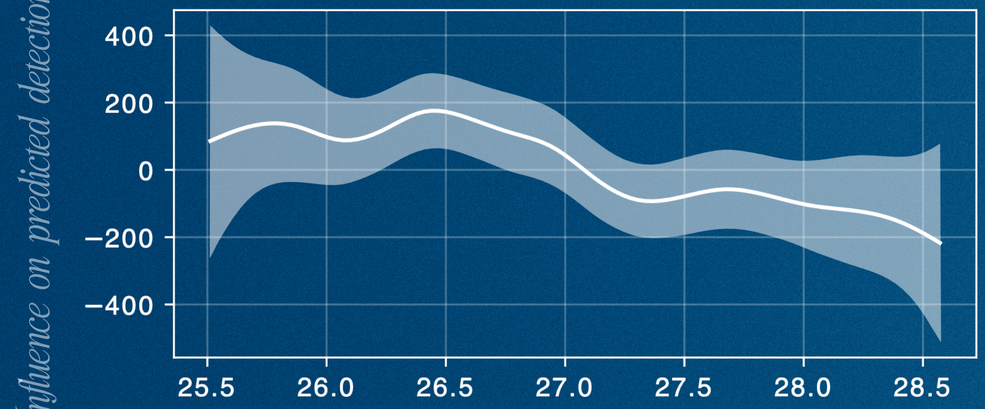
R^2 value of the model : 53%
= these parameters explains half of the observations

RESULTS : Humpback whale



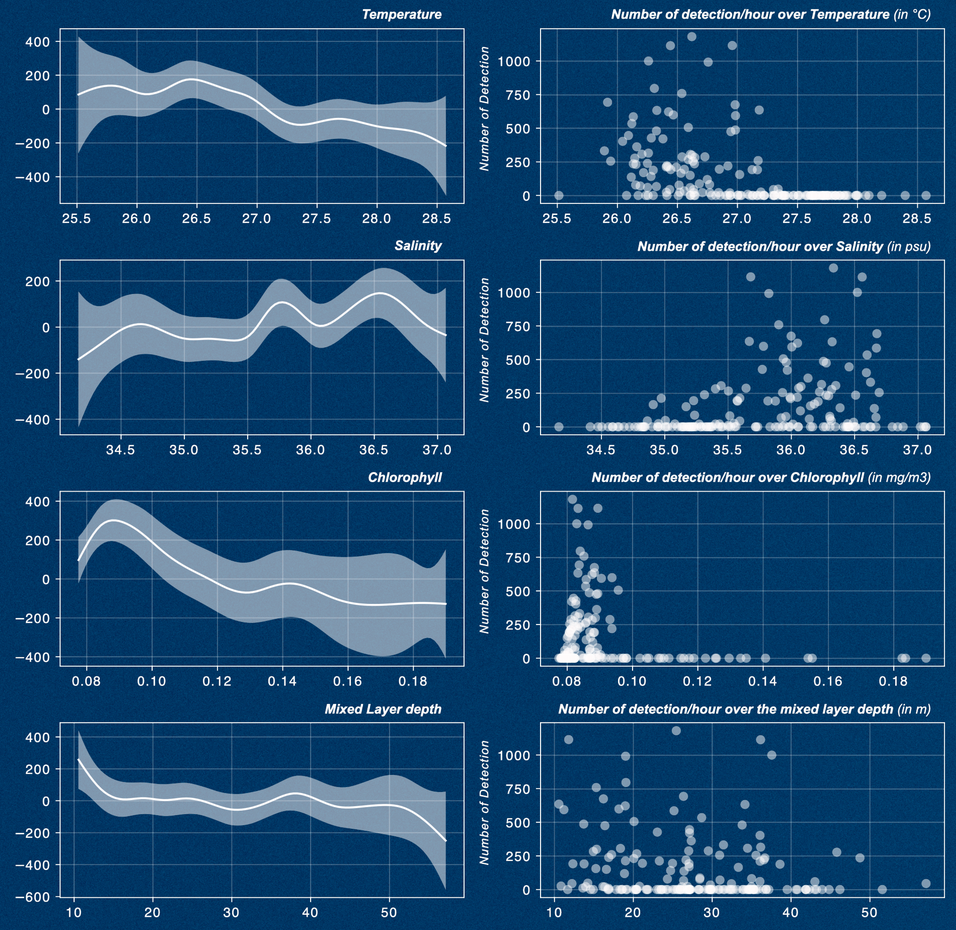
2. VARIABLE PARAMETER

Temperature

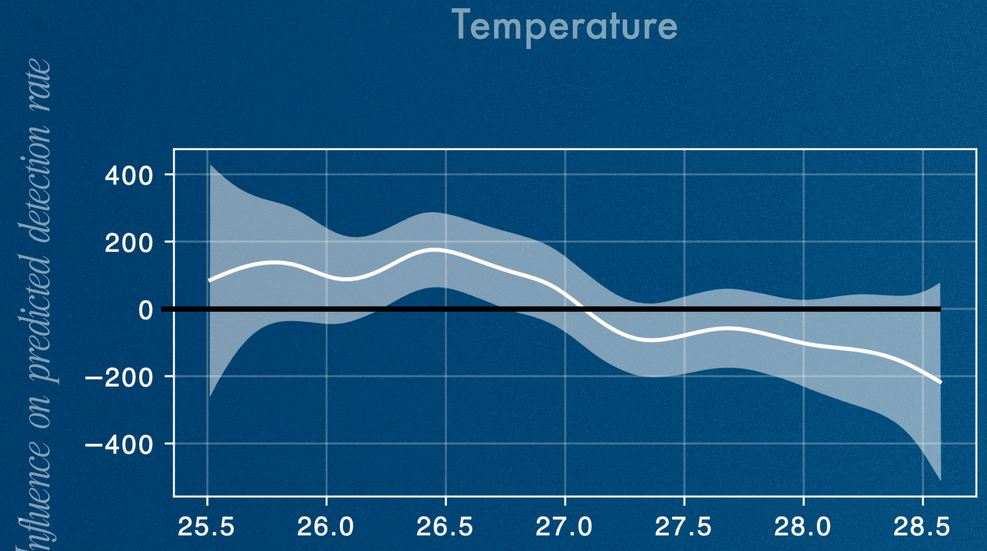


CENTRE int. d'INTELLIGENCE ARTIFICIELLE EN ACOUSTIQUE NATURELLE

RESULTS : Humpback whale

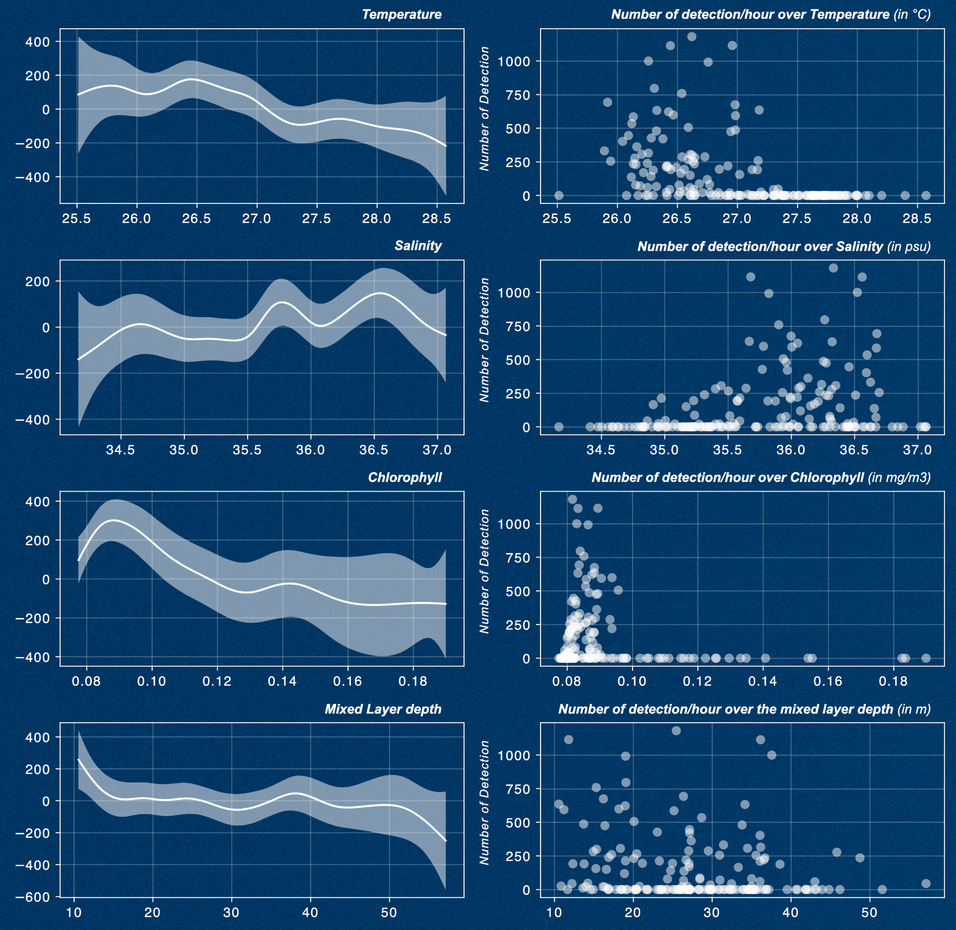


2. VARIABLE PARAMETER

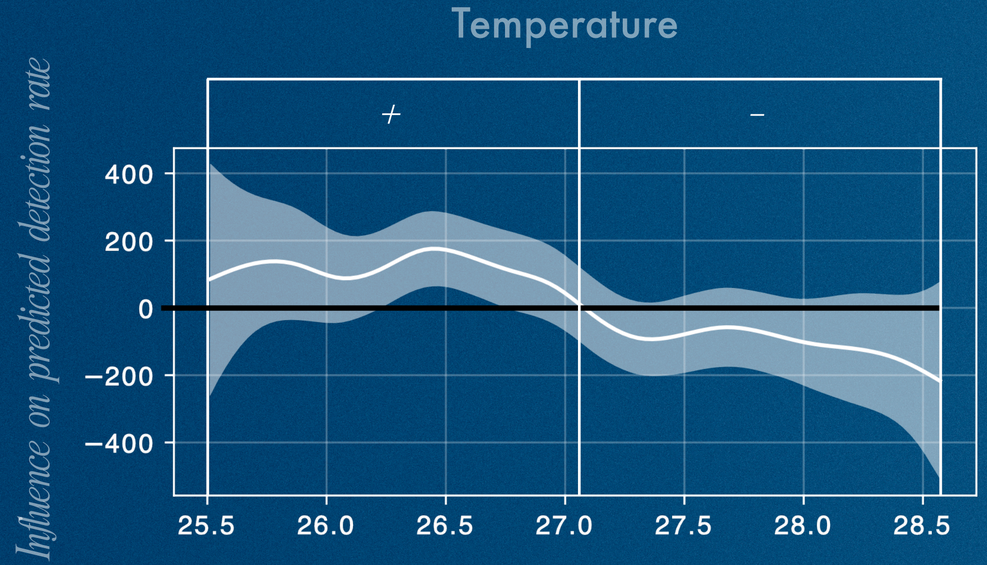


CENTRE int. d'INTELLIGENCE ARTIFICIELLE EN ACOUSTIQUE NATURELLE

RESULTS : Humpback whale

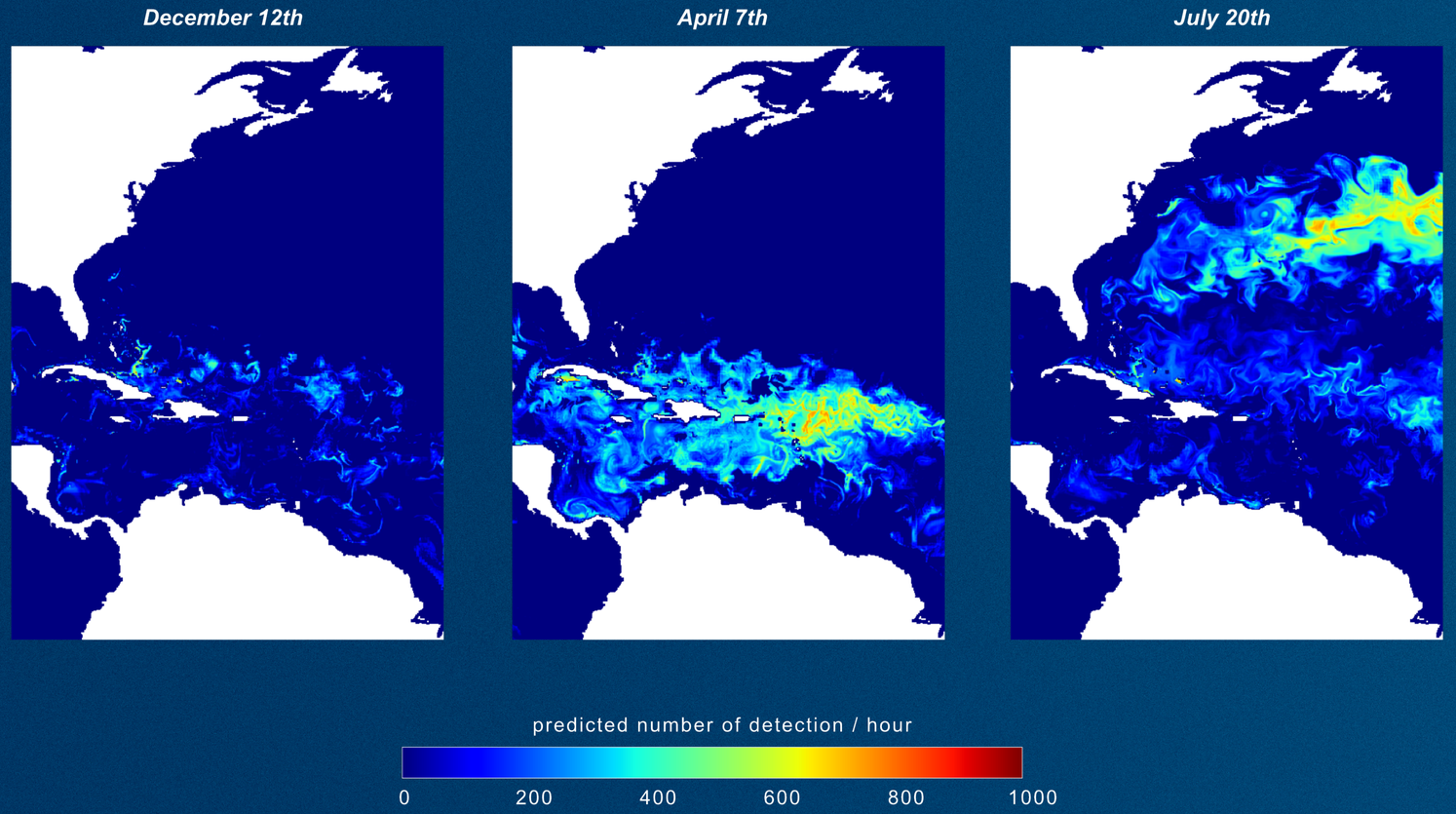


2. VARIABLE PARAMETER



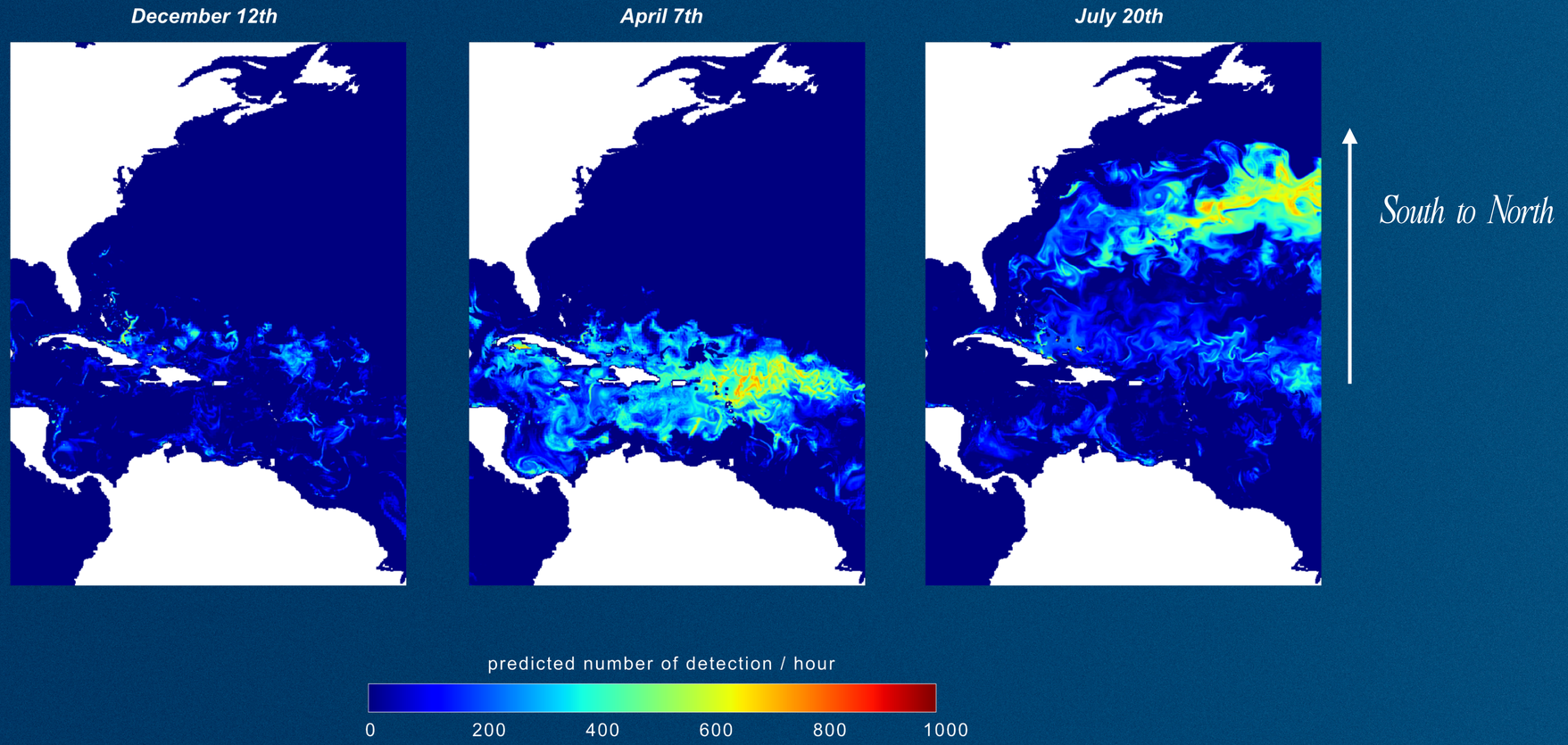
Temperature is significantly associated to the presence of humpback whale, with a decrease when the temperature > 27.1°C

RESULTS : Humpback whale



Predicted detection rate of Humpback whale between December 2020 and July 2021

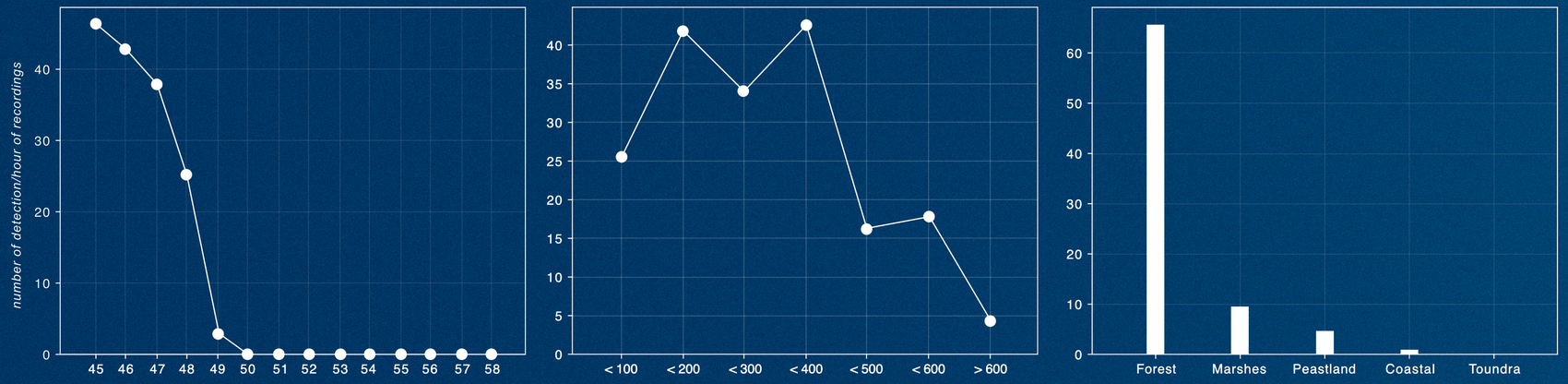
RESULTS : Humpback whale



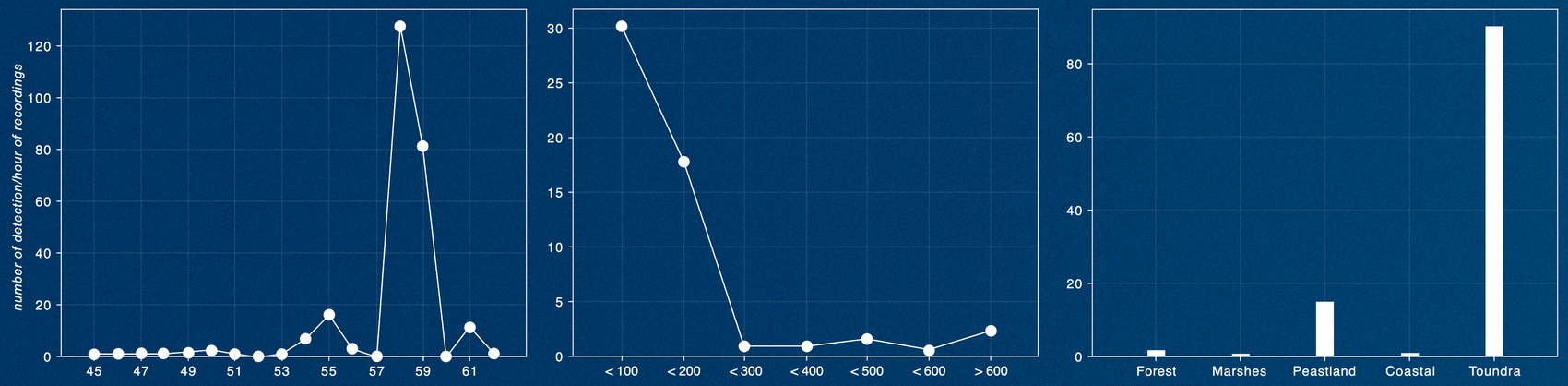
Predicted detection rate of Humpback whale between December 2020 and July 2021

RESULTS : Birds

OVEN - Ovenbird *(Seiurus aurocapilla)*



WCSP - White-crowned Sparrow *(Zonotrichia leucophrys)*



LATITUDE

ALTITUDE

HABITAT

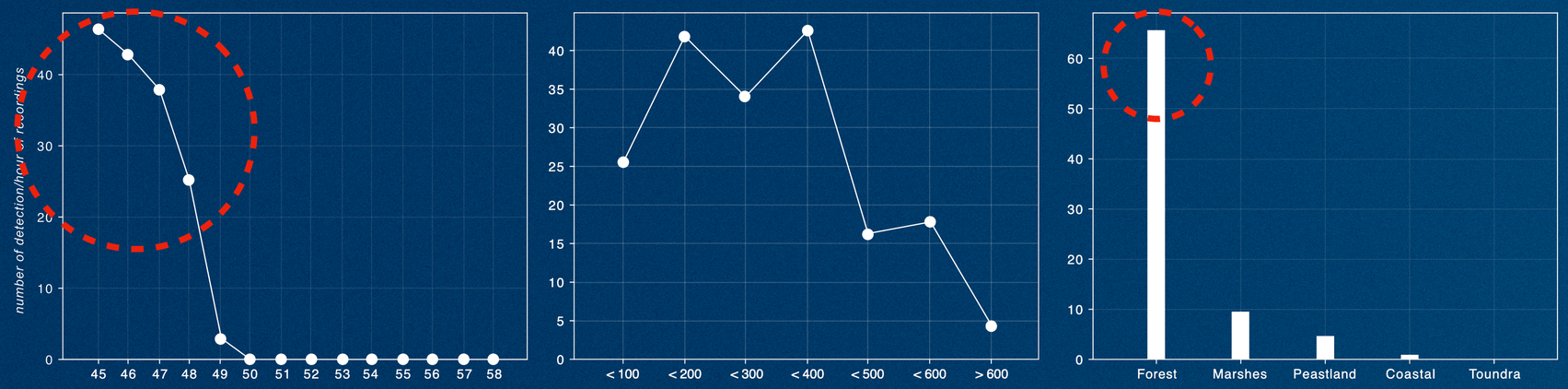
1. FIXED PARAMETER

Example for 2 of the 27 species

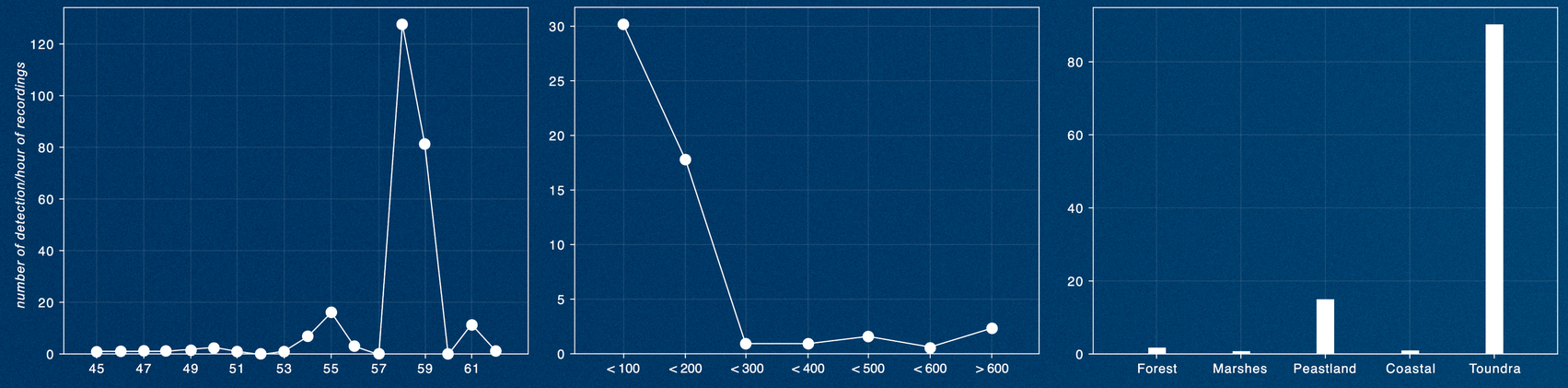
CENTRE int. d'INTELLIGENCE ARTIFICIELLE EN ACOUSTIQUE NATURELLE

RESULTS : Birds

OVEN - Ovenbird *(Seiurus aurocapilla)*



WCSP - White-crowned Sparrow *(Zonotrichia leucophrys)*



LATITUDE ALTITUDE HABITAT

1. FIXED PARAMETER

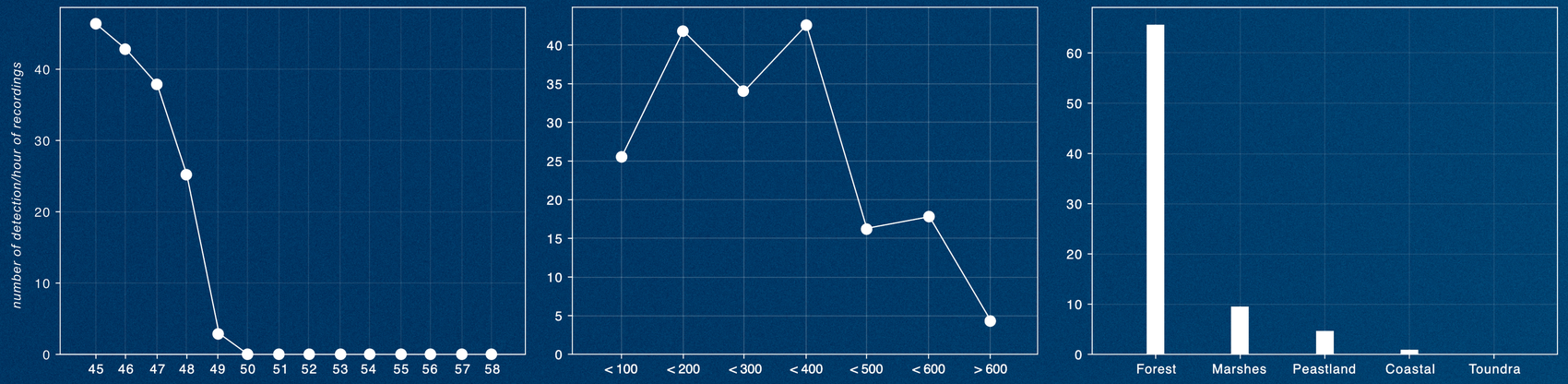
Ovenbird : preferences for forest at lower latitudes

White-crowned Sparrow : preferences for high latitude in tundra or peatland habitats

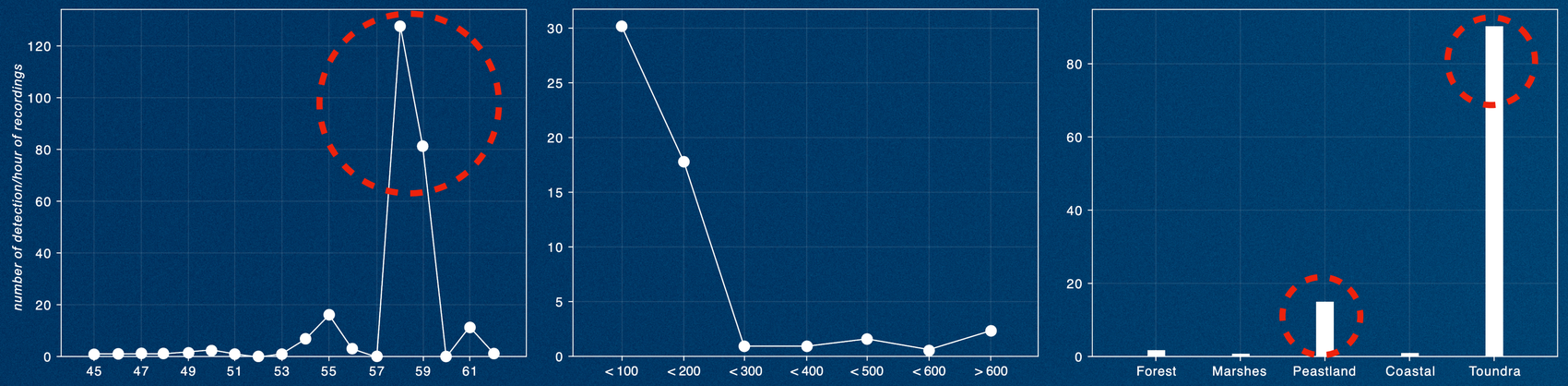
CENTRE int. d'INTELLIGENCE ARTIFICIELLE en ACOUSTIQUE NATURELLE

RESULTS : Birds

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LATITUDE ALTITUDE HABITAT

1. FIXED PARAMETER

Ovenbird : preferences for forest at lower latitudes

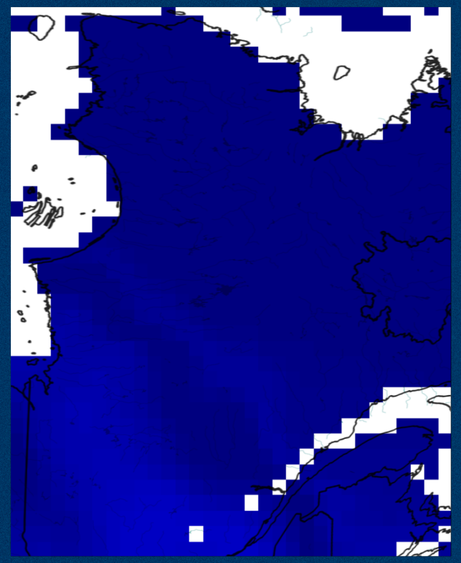
White-crowned Sparrow : preferences for high latitude in tundra or peatland habitats

CENTRE int. d'INTELLIGENCE ARTIFICIELLE en ACOUSTIQUE NATURELLE

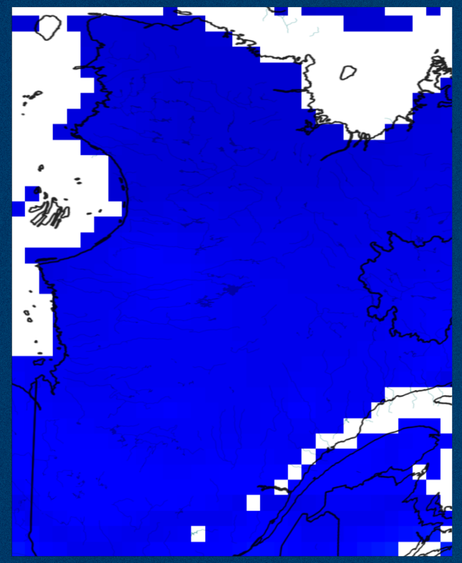
RESULTS : Birds

2. VARIABLE PARAMETER

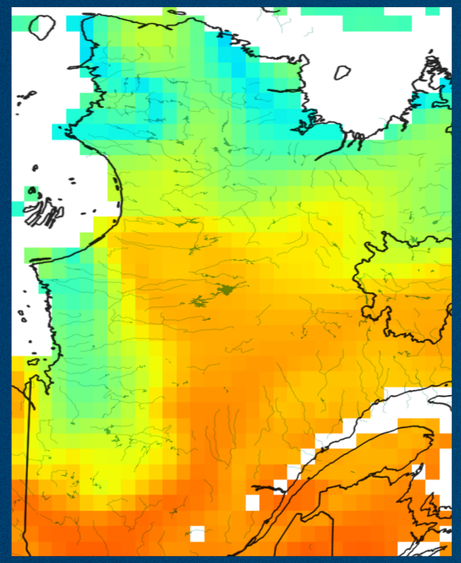
April 14th 2021



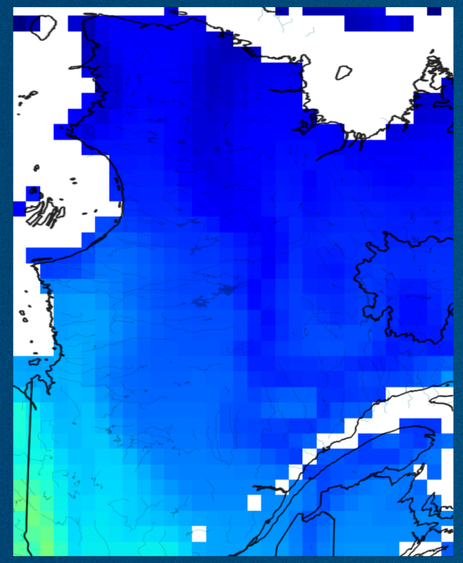
May 29th 2021



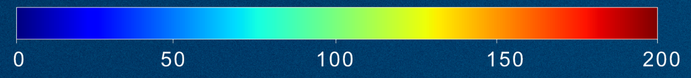
June 17th 2021



July 29th 2021



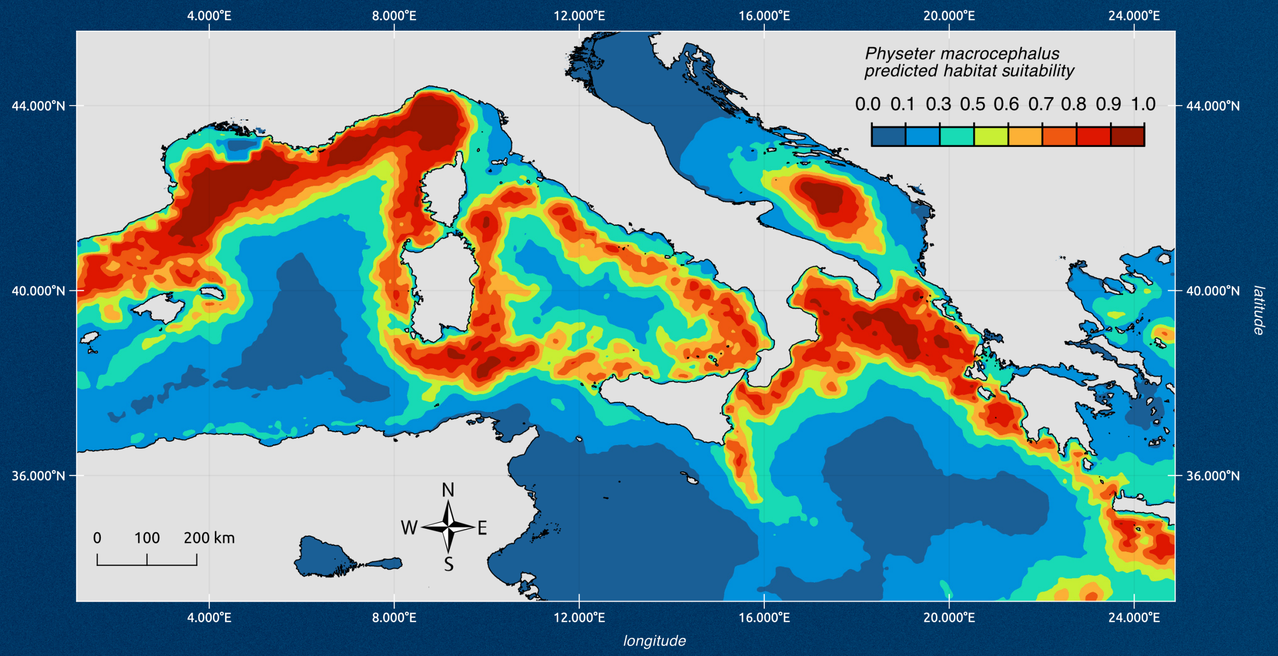
predicted number of detection / hour



Paramaters :

CENTRE int. d'INTELLIGENCE ARTIFICIELLE EN ACOUSTIQUE NATURELLE

RESULTS : Sperm whale

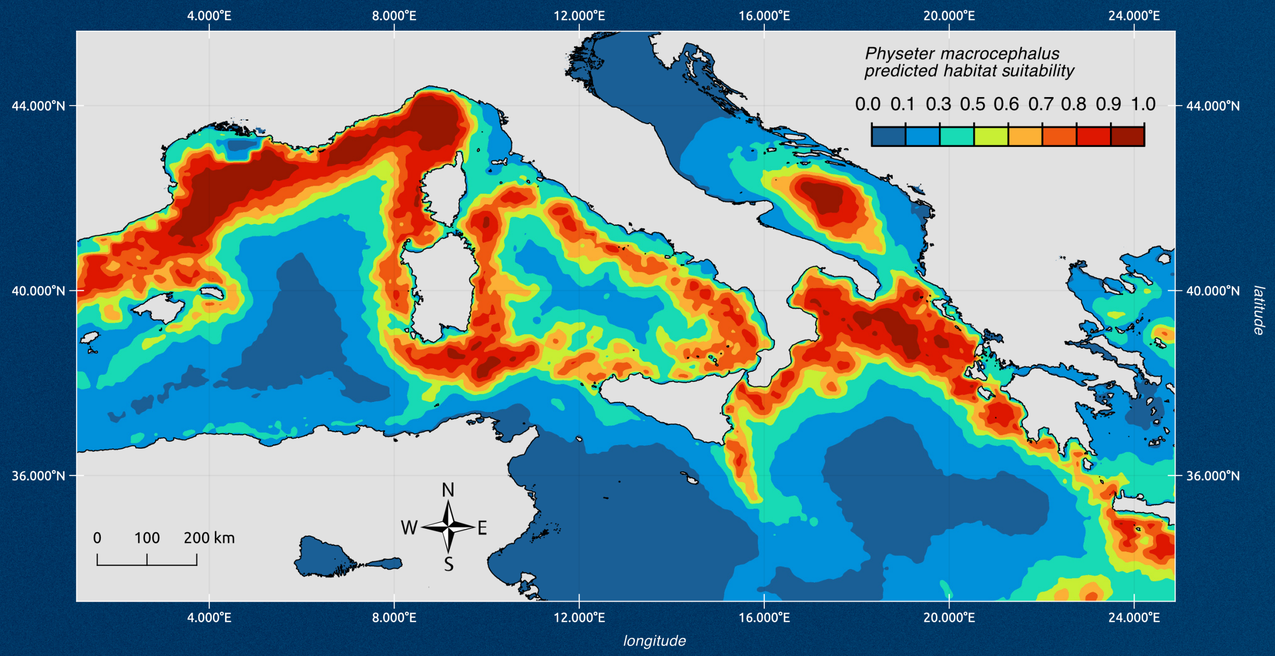


AUC of 96.5% over the test set (Ocean Biodiversity Information System dataset)

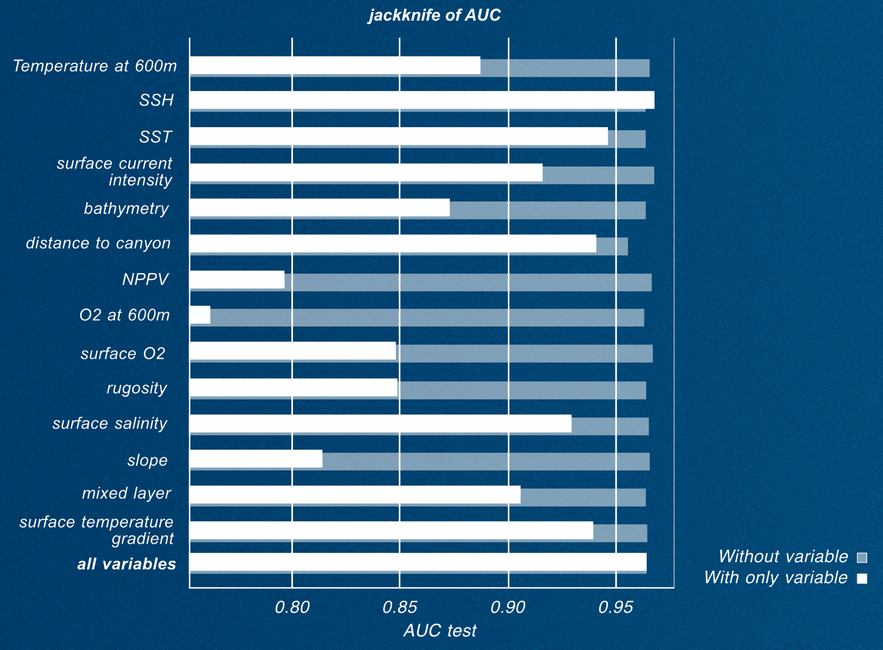
70% of the global observations are inside the area above 0.5 of confidence

Predicted map of suitable habitat for sperm whale in the Mediterranean Sea along the impact of each parameters

RESULTS : Sperm whale



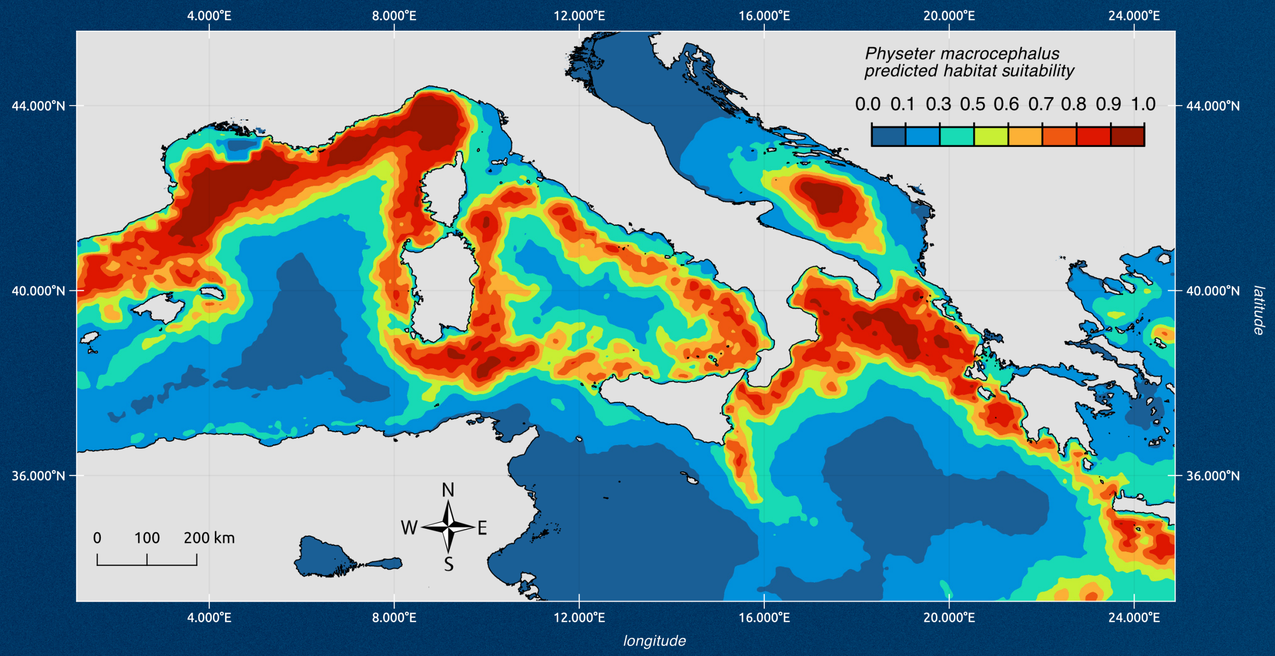
Contribution in the model



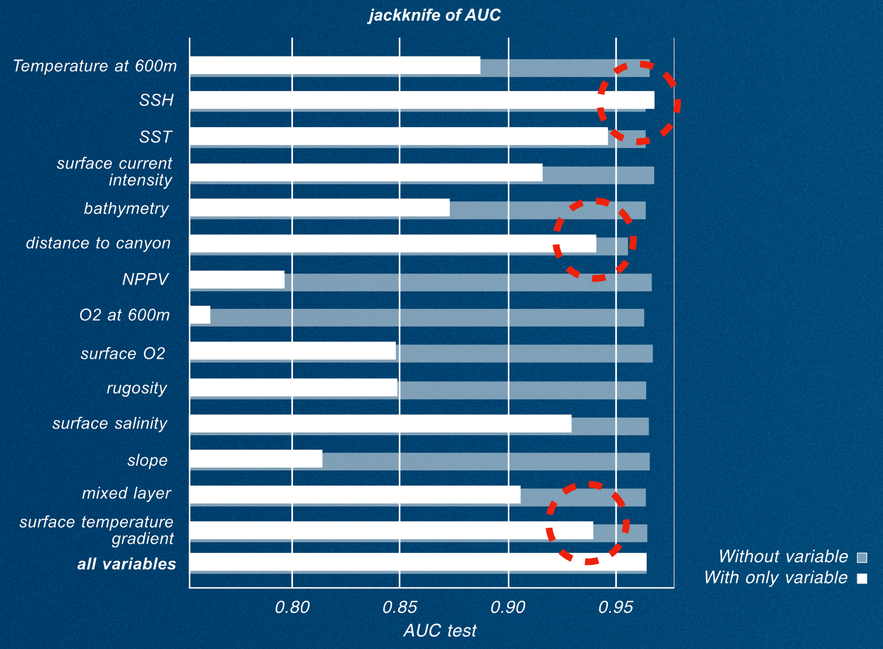
Predicted map of suitable habitat for sperm whale in the Mediterranean Sea along the impact of each parameters

CENTRE int. d'INTELLIGENCE ARTIFICIELLE en ACOUSTIQUE NATURELLE

RESULTS : Sperm whale



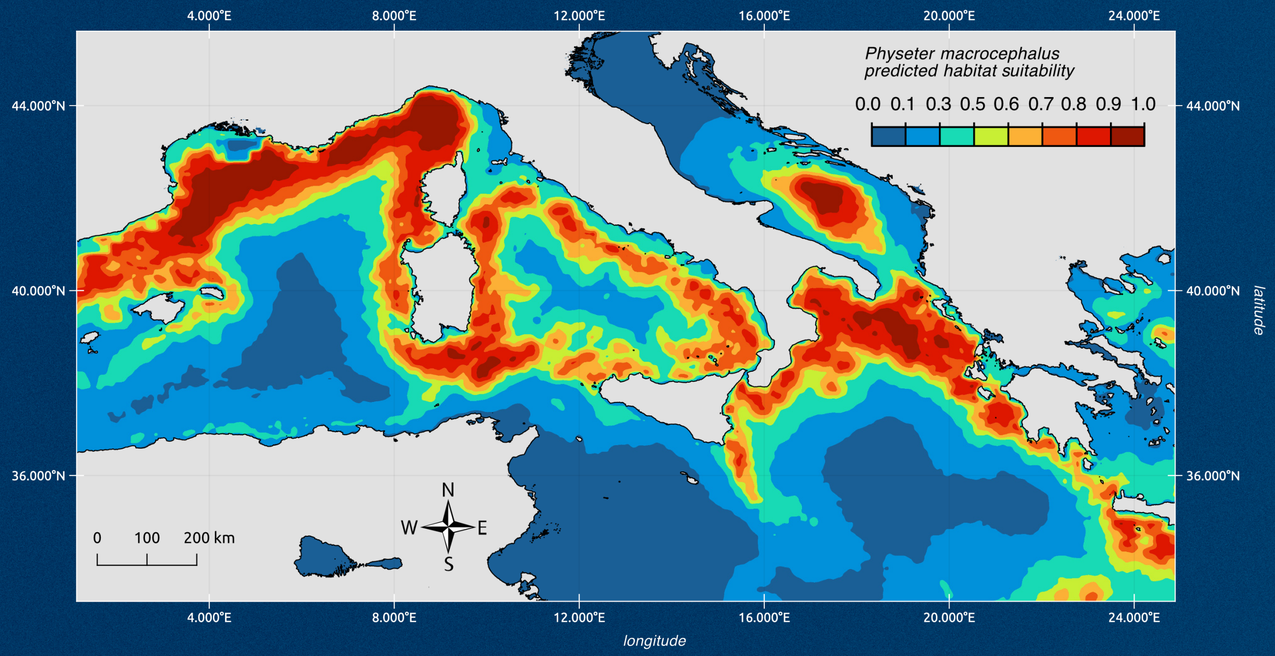
Contribution in the model



Predicted map of suitable habitat for sperm whale in the Mediterranean Sea along the impact of each parameters

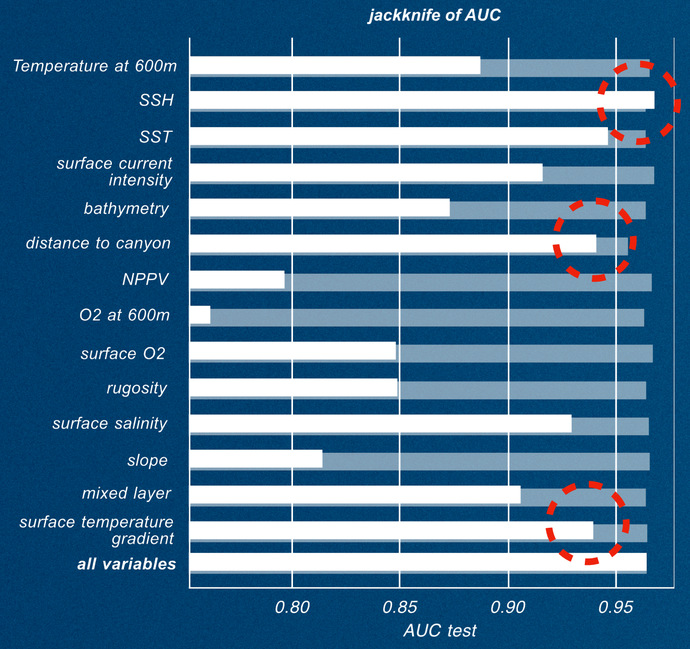
CENTRE int. d'INTELLIGENCE ARTIFICIELLE en ACOUSTIQUE NATURELLE

RESULTS : Sperm whale



Contribution in the model

Influence on suitability



↗ *when lower SSH*

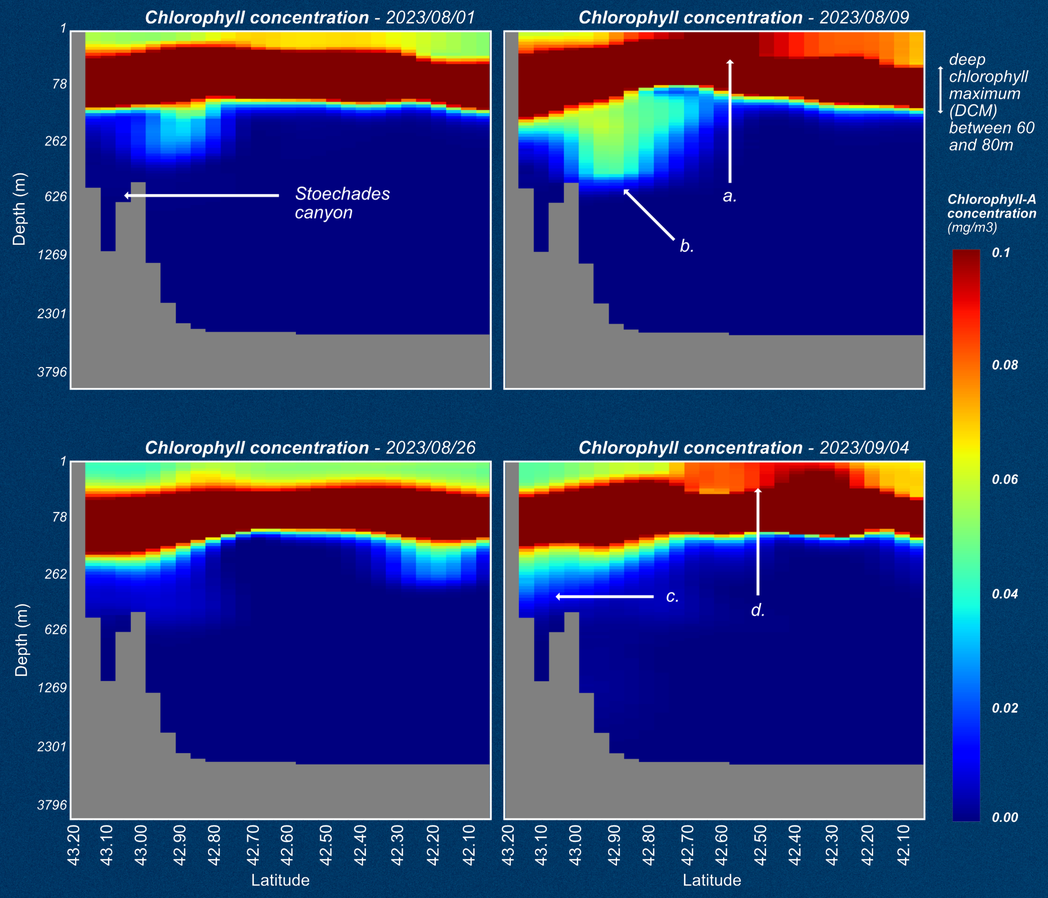
↗ *near canyons*

↗ *when delta > 0.5°C*

Predicted map of suitable habitat for sperm whale in the Mediterranean Sea along the impact of each parameters

CENTRE int. d'INTELLIGENCE ARTIFICIELLE en ACOUSTIQUE NATURELLE

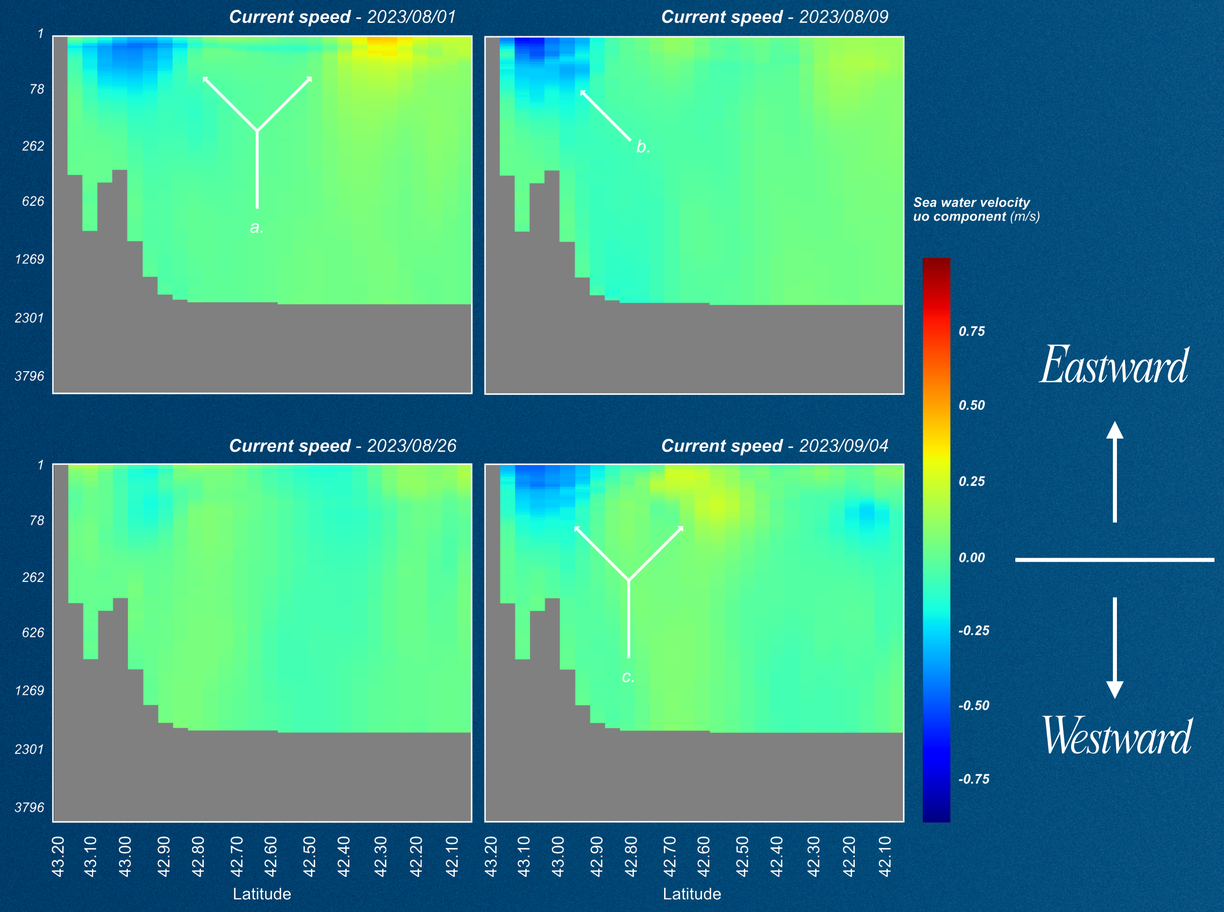
RESULTS : Sperm whale and Stoechades canyon



- *Potential downwelling = increase of the chlorophyll concentration in the deep waters of the canyon*
- *Increase of the chlorophyll concentration at the surface offshore*

RESULTS : Sperm whale and Stoechades canyon

- *Strong current inside the canyon : orientation to the northern current*
- *Front between 2 currents : Northern current + Balearic Return Current = divergence = lower ssh and upwelling which explain the higher concentration of chlorophyll*

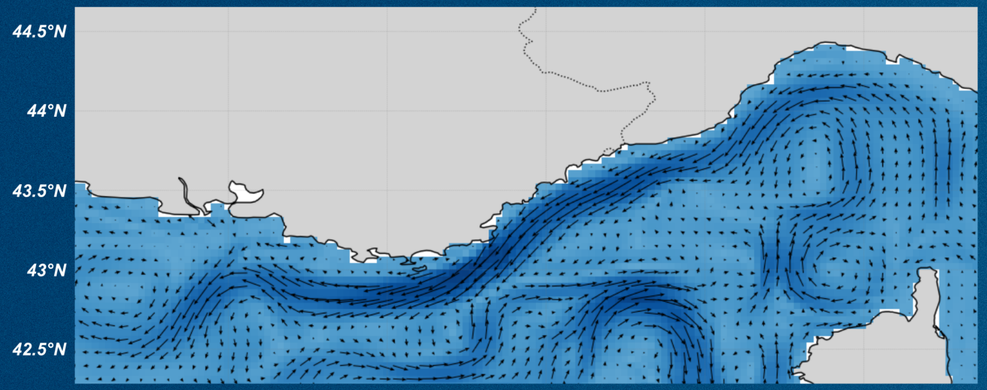


RESULTS : Sperm whale and surface currents

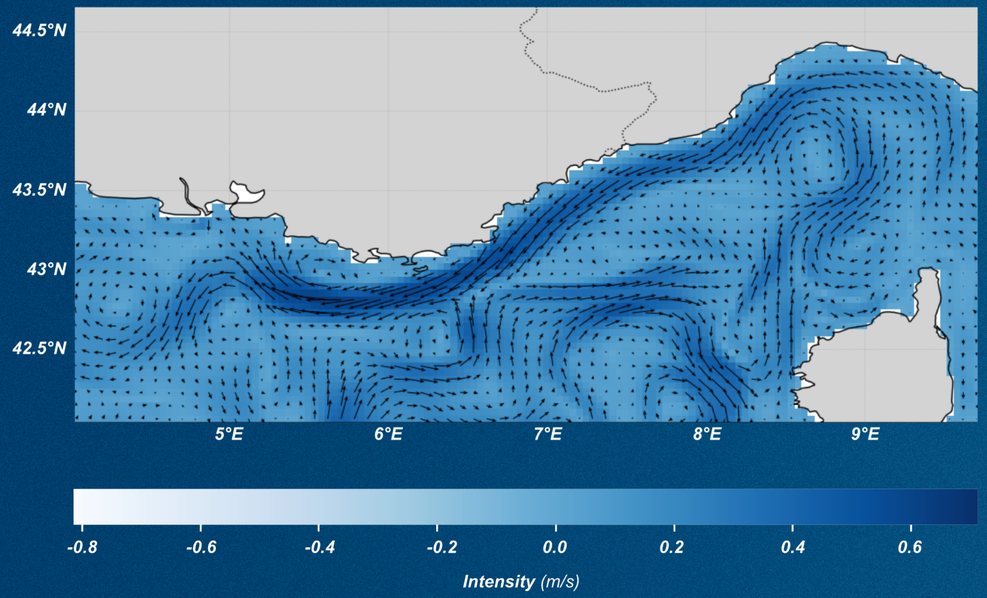
1 month after = Observations of sperm whale in the canyon and between Toulon and Nice

Sea surface current = Front between Northern current and the Balearic Return Current (BRC)

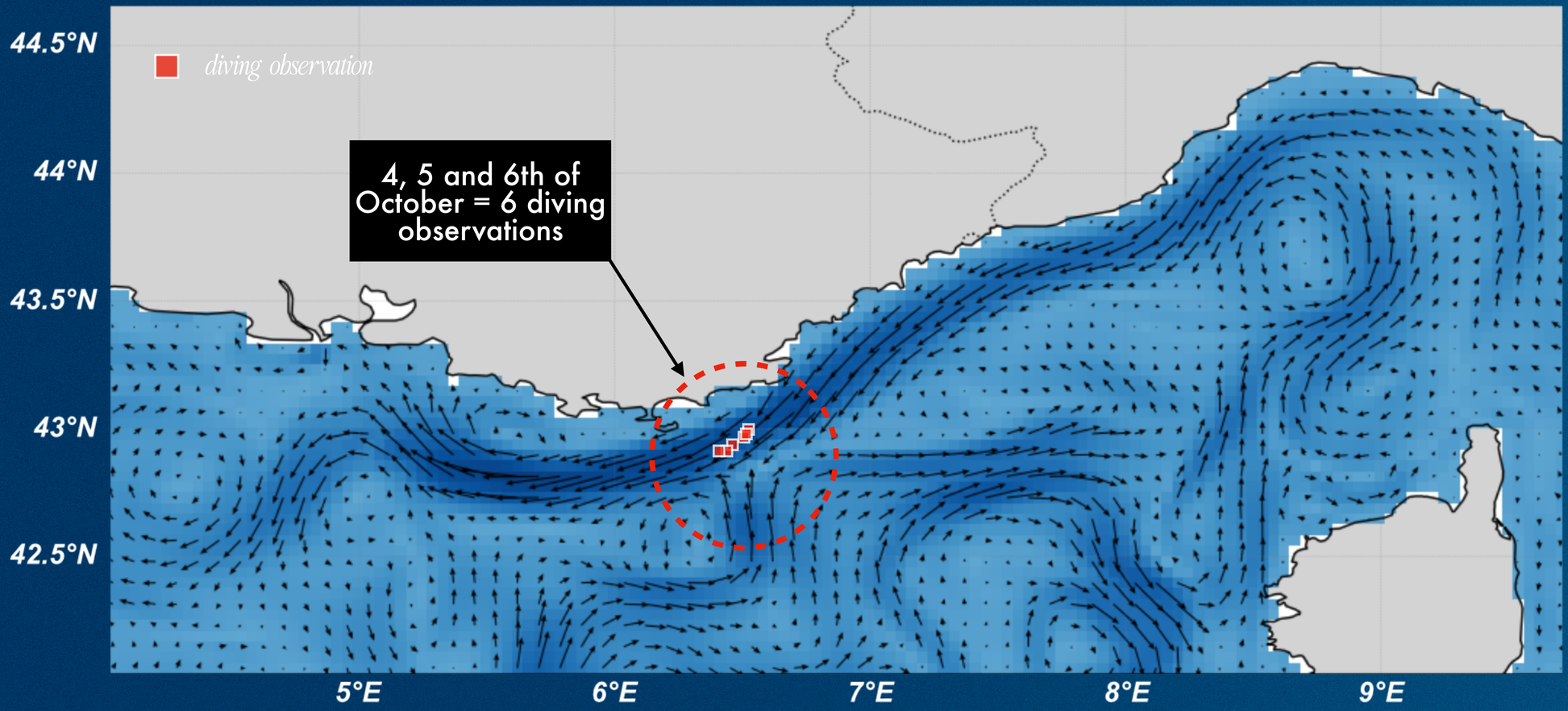
Sea surface current intensity - 28th September 2023



Sea surface current intensity - 2nd October 2023

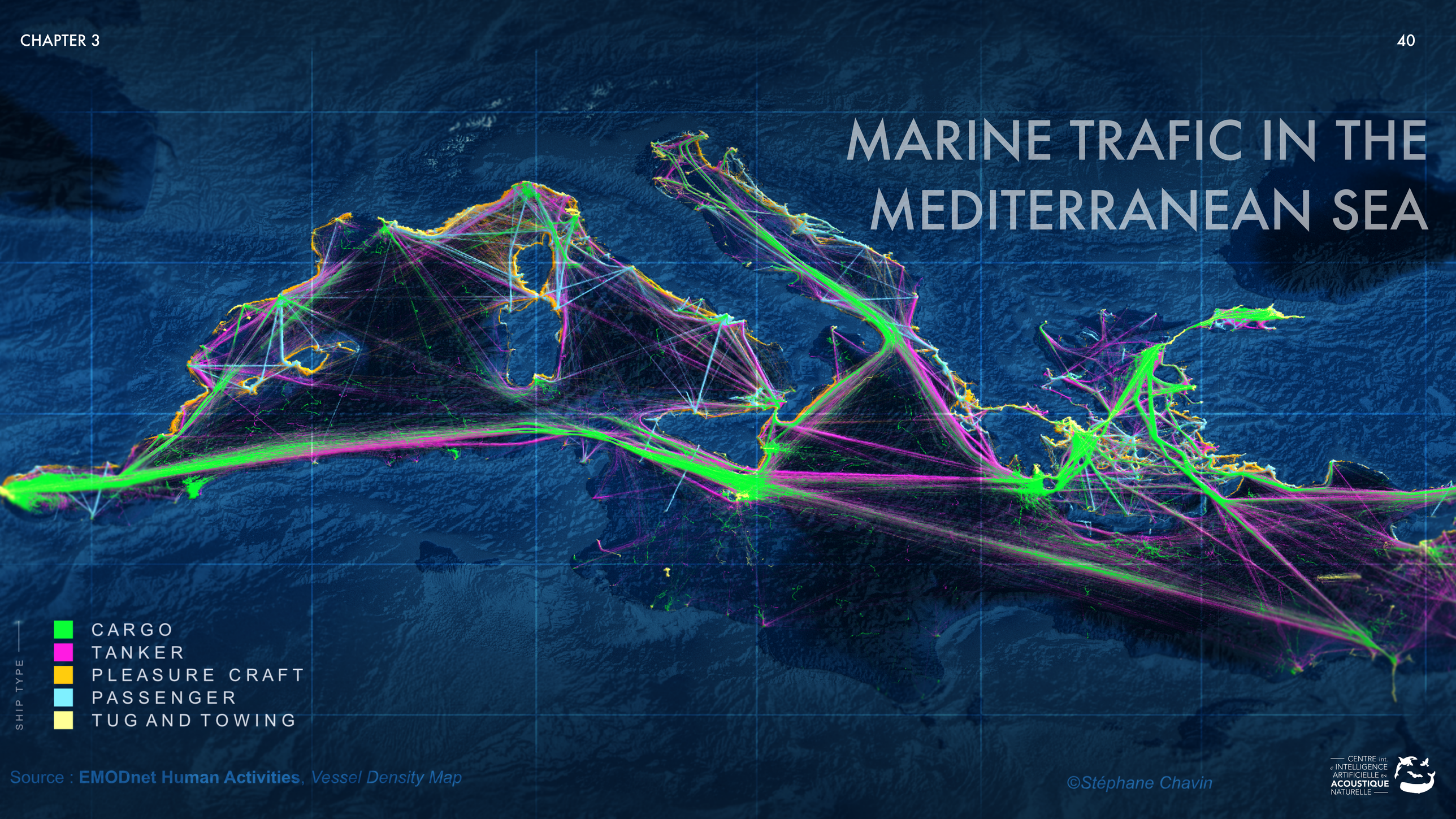


RESULTS : Sperm whale and surface currents



HOW TO APPLY THESES RESULTS TO CONSERVATION ?

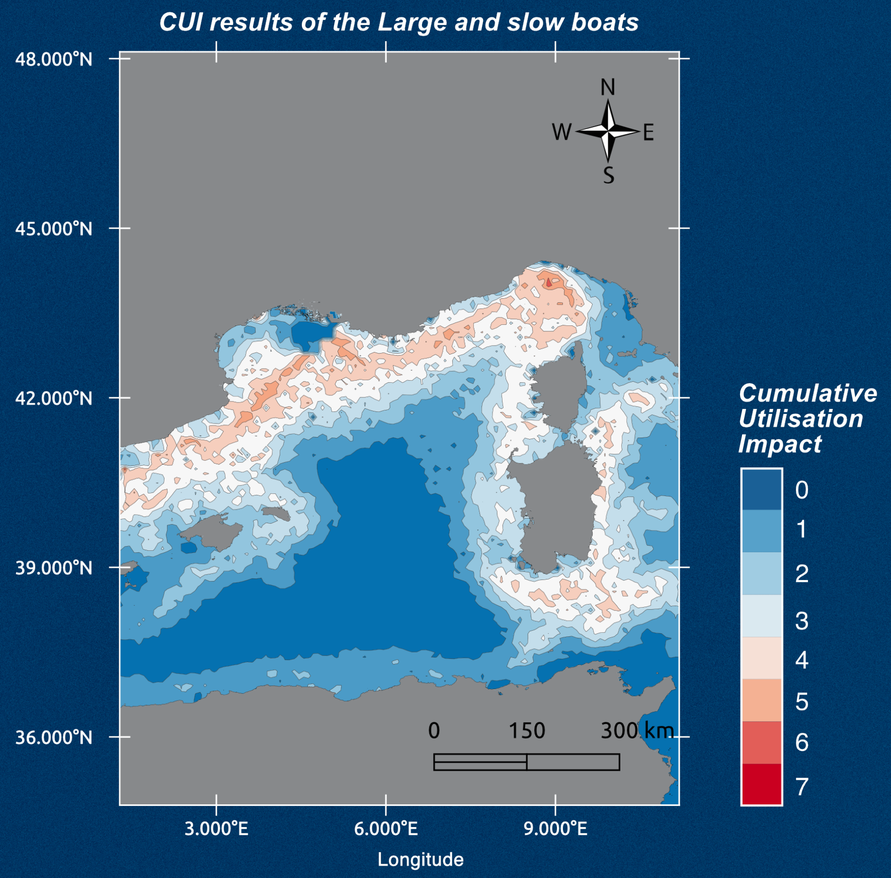
MARINE TRAFIC IN THE MEDITERRANEAN SEA



Source : **EMODnet Human Activities**, *Vessel Density Map*

©Stéphane Chavin

CENTRE int. d'INTELLIGENCE ARTIFICIELLE en ACOUSTIQUE NATURELLE

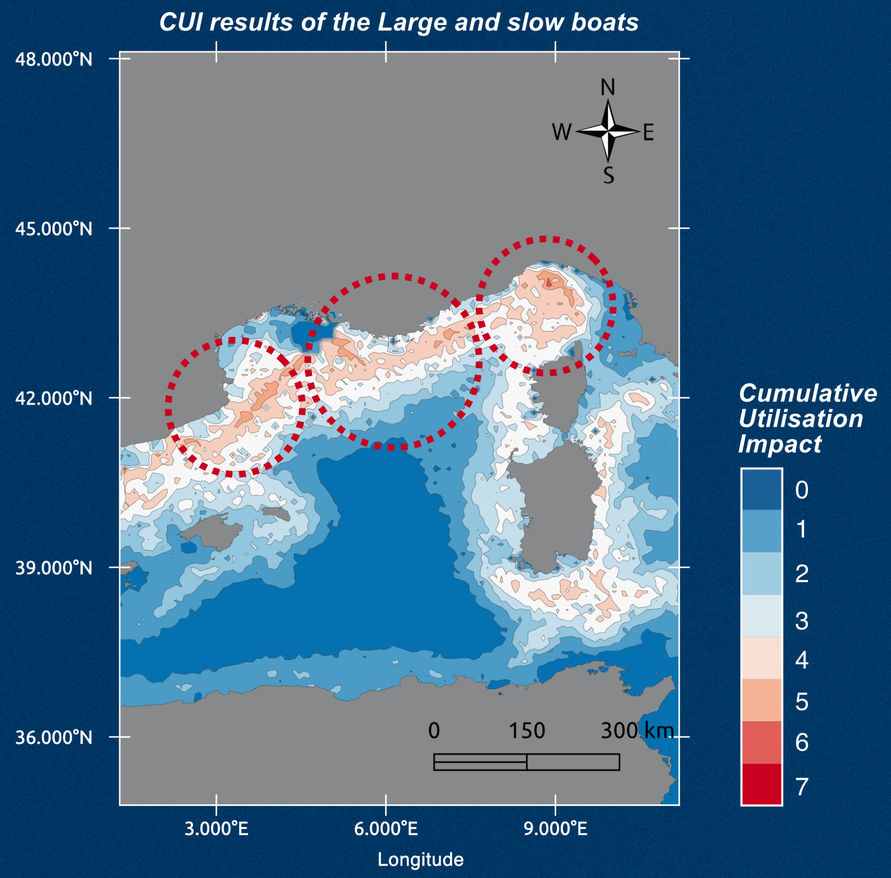


LARGE BOATS (HIGHER RISK 12/20)

- **Cargo, Tanker, Ferries :** *Can go at high speed (> 15 knots) but have less control on their trajectories = canot avoid the animal*

$$CUI = \sum_{i=1}^{n} \sum_{j=1}^{m} D_i \times S_j \times u_{ij}$$

Di : normalised (0-1) log transformed value of the intensity of the anthropogenic impact;
Sj : the probability of the species j;
uij : the weight of the impact of I on the species j

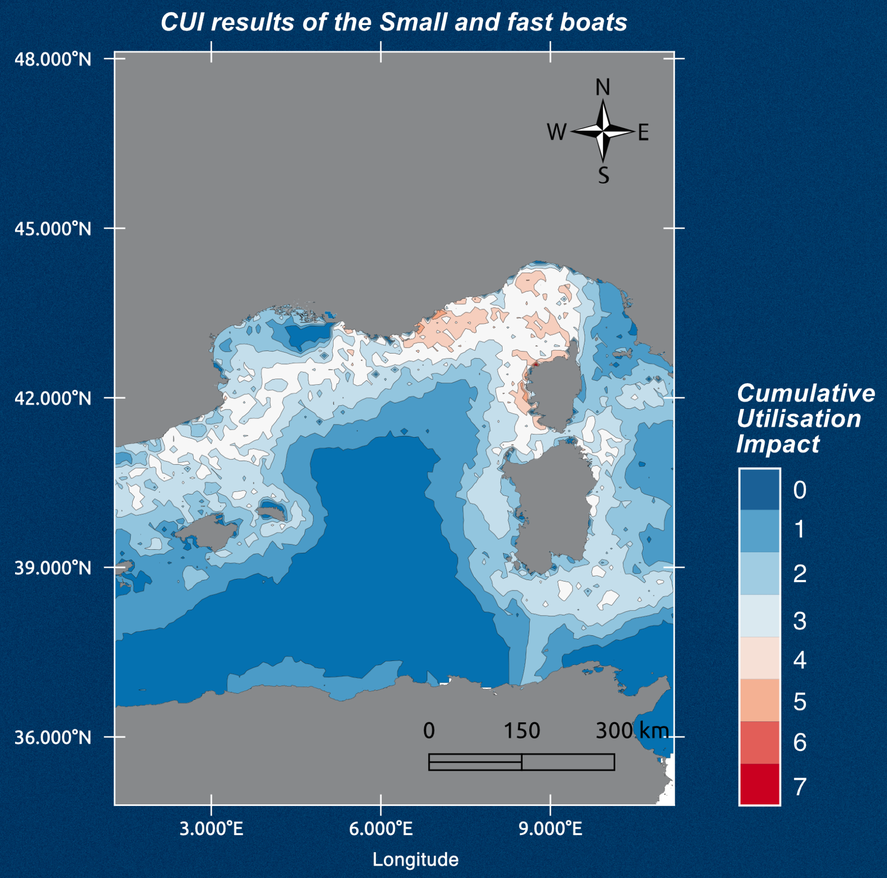


LARGE BOATS (HIGHER RISK 12/20)

- **Cargo, Tanker, Ferries :** *Can go at high speed (> 15 knots) but have less control on their trajectories = canot avoid the animal*

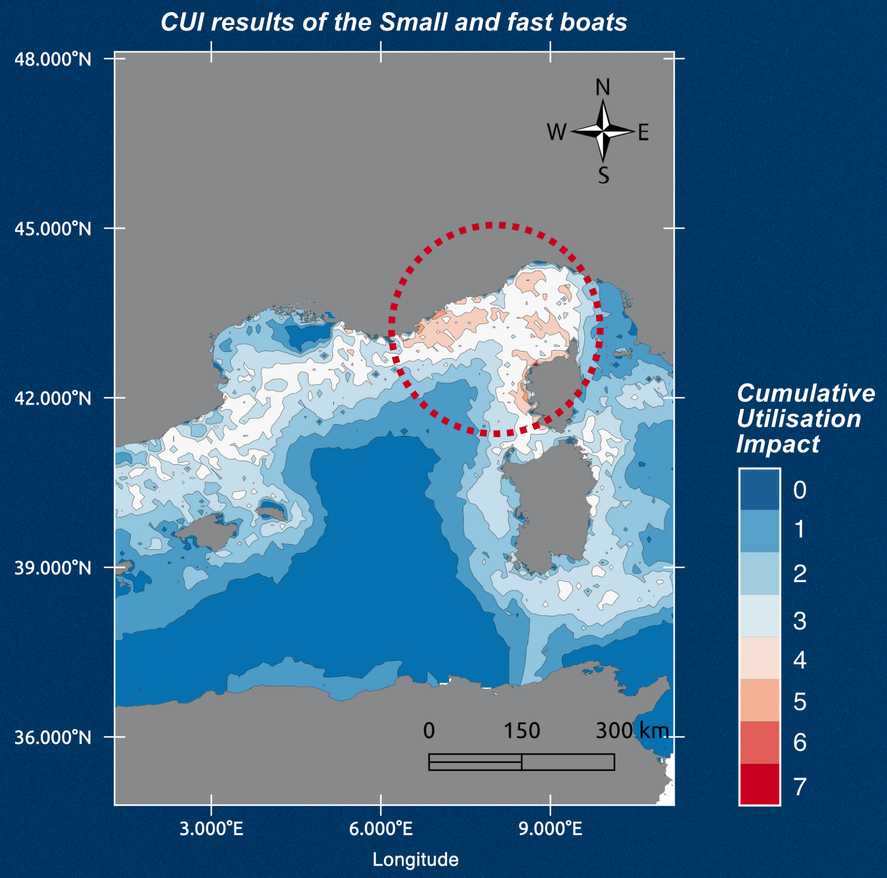
- **Risk area:** *Costa Brava (Spain), Marseille-Toulon (France) and Genoa (Italy)*

CENTRE int. d'INTELLIGENCE ARTIFICIELLE en ACOUSTIQUE NATURELLE



SMALL BOATS (10/20)

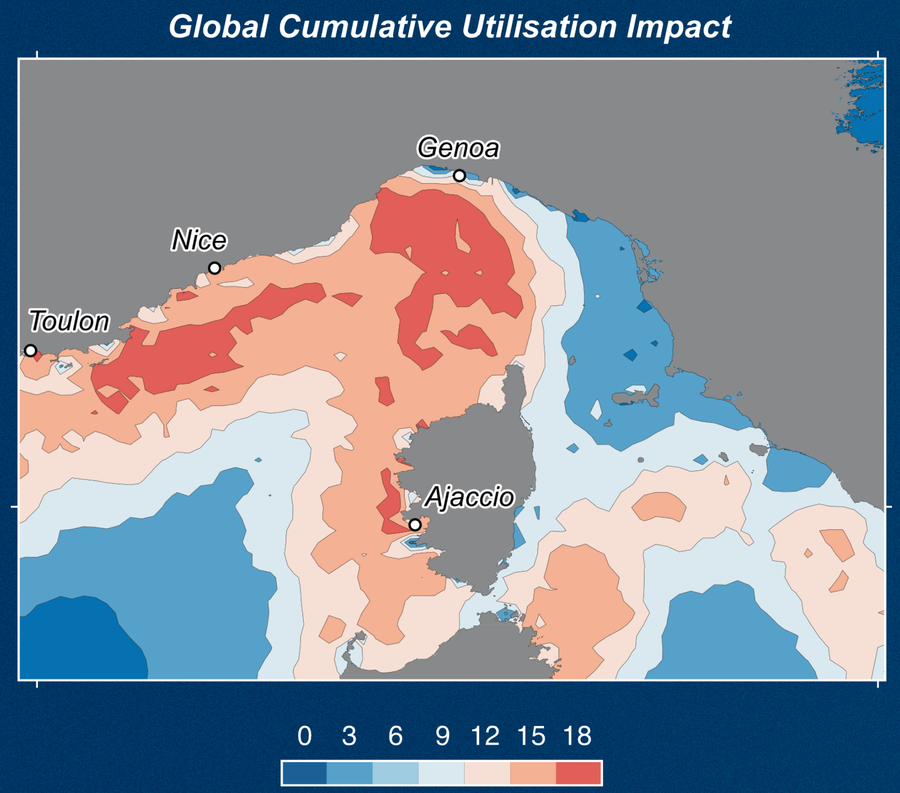
- **Pleasure craft :** *Can go high speed (> 20 knots) but have more control on their trajectories = can avoid the animal*



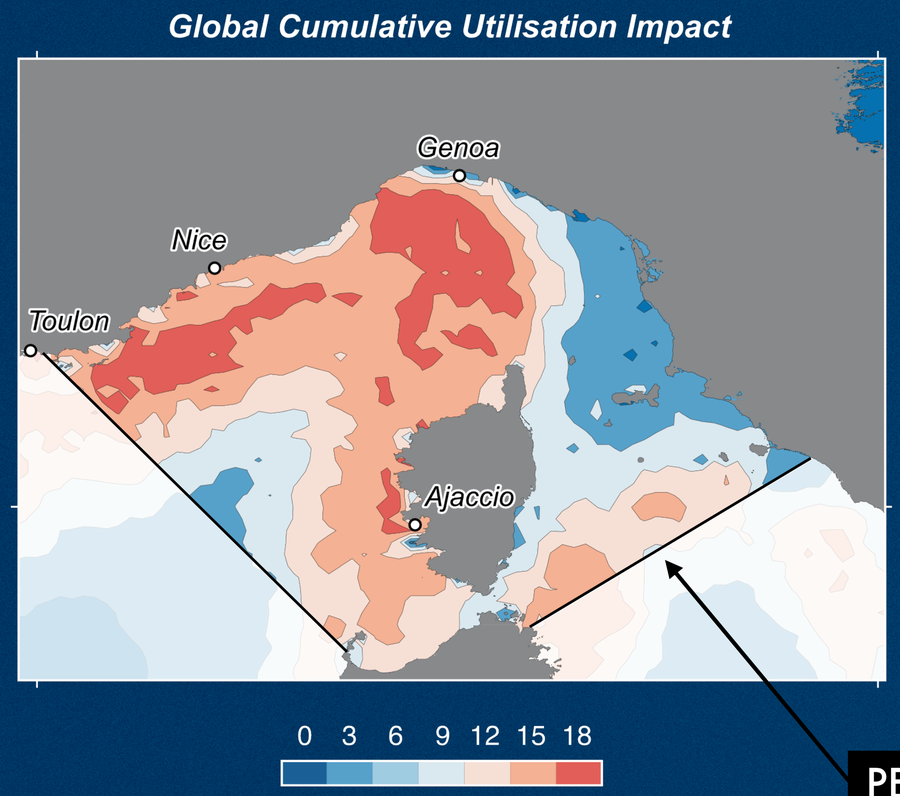
SMALL BOATS (10/20)

- **Pleasure craft :** *Can go high speed (> 20 knots) but have more control on their trajectories = can avoid the animal*

- **Risk area:** *Between Toulon and Genoa (Italy) until Corsica*



ALL BOATS TOGETHER



ALL BOATS TOGETHER

- *The impact is almost 2 times higher in the Pelagos Sanctuary rather than in the whole Mediterranean Sea*

Solutions : a decrease to 10 knots has been shown to reduce the fatality rate of collision by up to 45%

Humpback whale

CREATION OF A VOCAL REPERTOIRE + YOLOV5 MODEL AND ANALYSIS OF MULTI YEAR RECORDINGS FROM BREEDING GROUND

The potential rising of the sea surface temperature can change breeding habits : location or timing ?

Sperm Whale

ANALYSIS OF > 200 MULTI YEAR VISUAL OBSERVATIONS BETWEEN MARSEILLE AND MONACO, AND HABITAT MAPPING

Sperm whale habitat is linked to the canyons which could be more prone to upwelling or downwelling. This could help defining area of restriction for marine traffic

Birds of Québec

YOLOV5 MODEL FOR 27 SPECIES, ANALYSIS OF THE RECORDINGS FROM 2016 UNTIL NOW REGARDING THE ENVIRONMENT

As some species have preferences for specific biome or type of tree, logging represent a threat for their breeding area

	+	-
YOLOv5	Speed, time frequency annotations, highly precise results	Require precise annotations and computing memory
MaxENT	Visual and easy	Only gives a global idea of the potential areas
GAM	Consider the multiple parameters	Risk of overfitting

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→ *We have to choose between having good recall but low precision or low precision but high recall*

	+	-
YOLOv5	Speed, time frequency annotations, highly precise results	Require precise annotations and computing memory
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→ *It is not a density or abundance estimation*

	+	-
YOLOv5	Speed, time frequency annotations, highly precise results	Require precise annotations and computing memory
MaxENT	Visual and easy	Only gives a global idea of the potential areas
GAM	Consider the multiple parameters	Risk of overfitting

Have more precision on the influence of each parameters

	+	-
YOLOv5	Speed, time frequency annotations, highly precise results	Require precise annotations and computing memory
MaxENT	Visual and easy	Only gives a global idea of the potential areas
GAM	Consider the multiple parameters	Risk of overfitting

It can be difficult to identify all the variables + some variables are dependent on other

There is a potential sampling biais

HOW TO USE DEEP LEARNING DETECTIONS FOR SPECIES DISTRIBUTION MODELING ?

PERSCPECTIVES & RECOMMENDATIONS

- *Should be considered depending on the objective of the project*

Sometimes, large database are not useful to answer the question, so manual analysis remains better

- *Work in collaboration with experts*

In order to have precise annotations

- *Create a substantial dataset with variabilities in the annotations*

Adapt the model to the reality of the recordings

- *Testing on independant and published datasets*

It is sometimes easier to be good on our personal dataset

- *Keeping in mind the potential of misalignment*

Models can learn the background or other type of features of the recordings

PERSCPECTIVES & RECOMMENDATIONS

- *Whats next ?*

THANK YOU

