Introduction to **acoustic telemetry** for **tracking fish**

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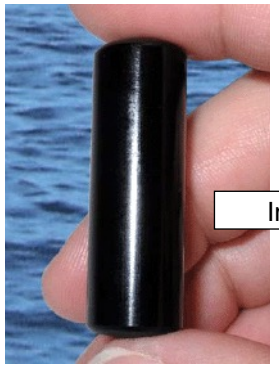
Mallorca Science School: Interdisciplinary Science for Marine and Coastal Conservation in a Changing World
Palma (Illes Balears)
October 20-26 2024

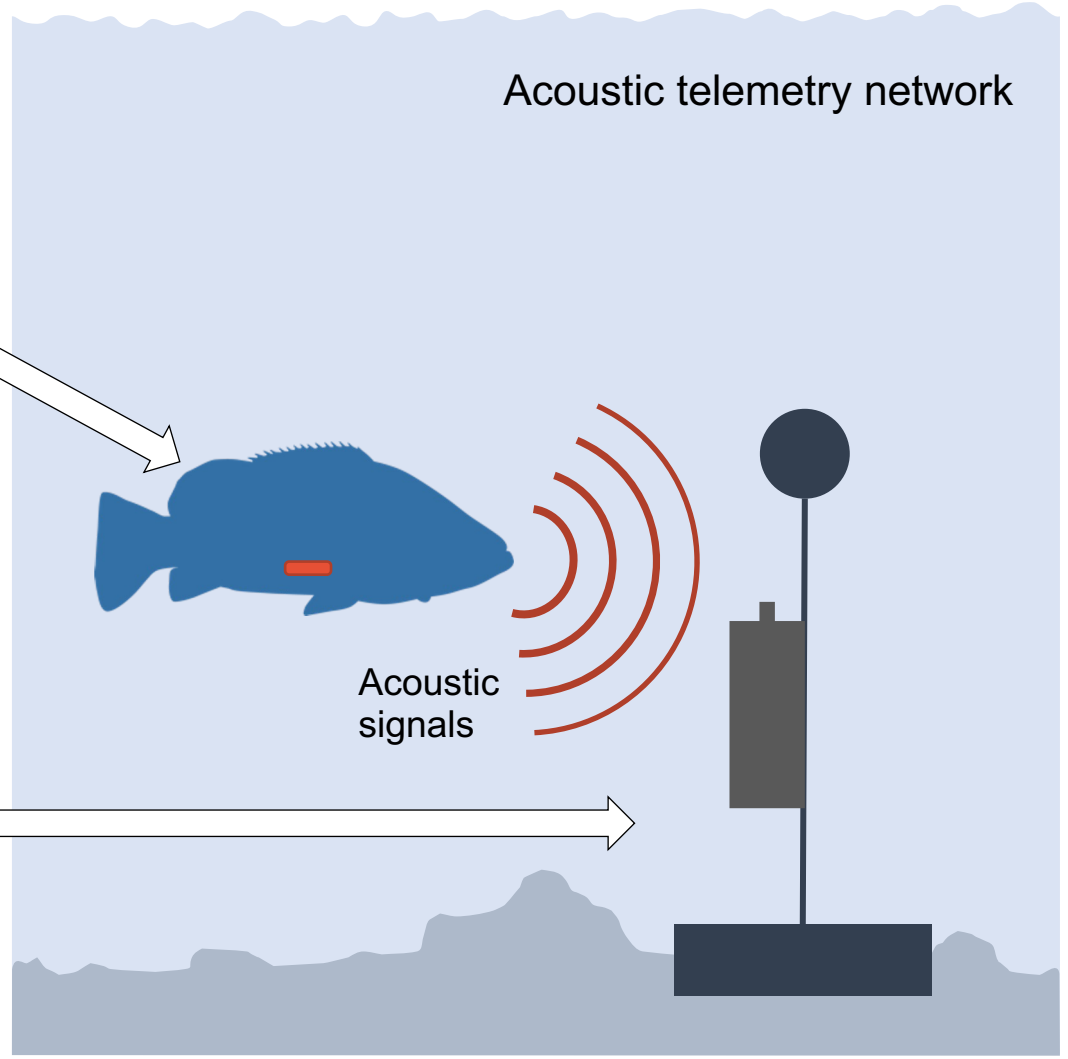
Acoustic Telemetry

Transmitter



Implantation

Receiver

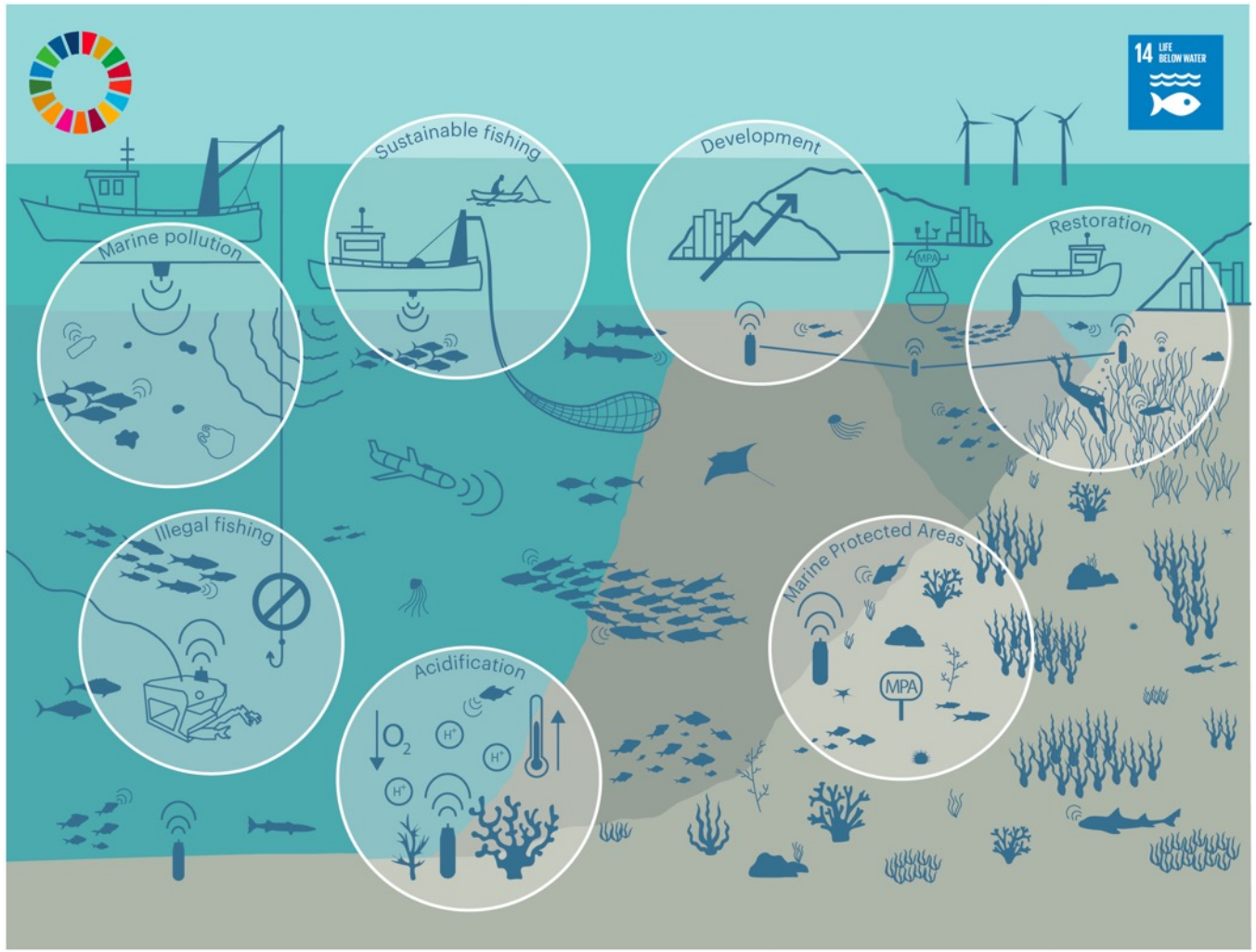


Acoustic Telemetry

Key tool to study the **movement and behaviour** of aquatic organisms

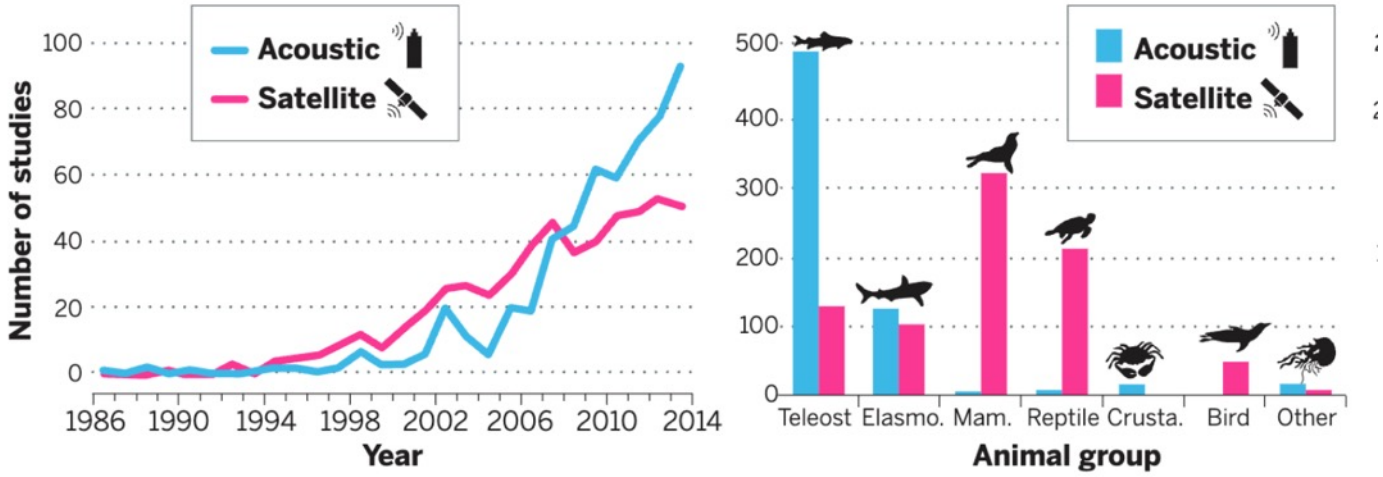
Applications:

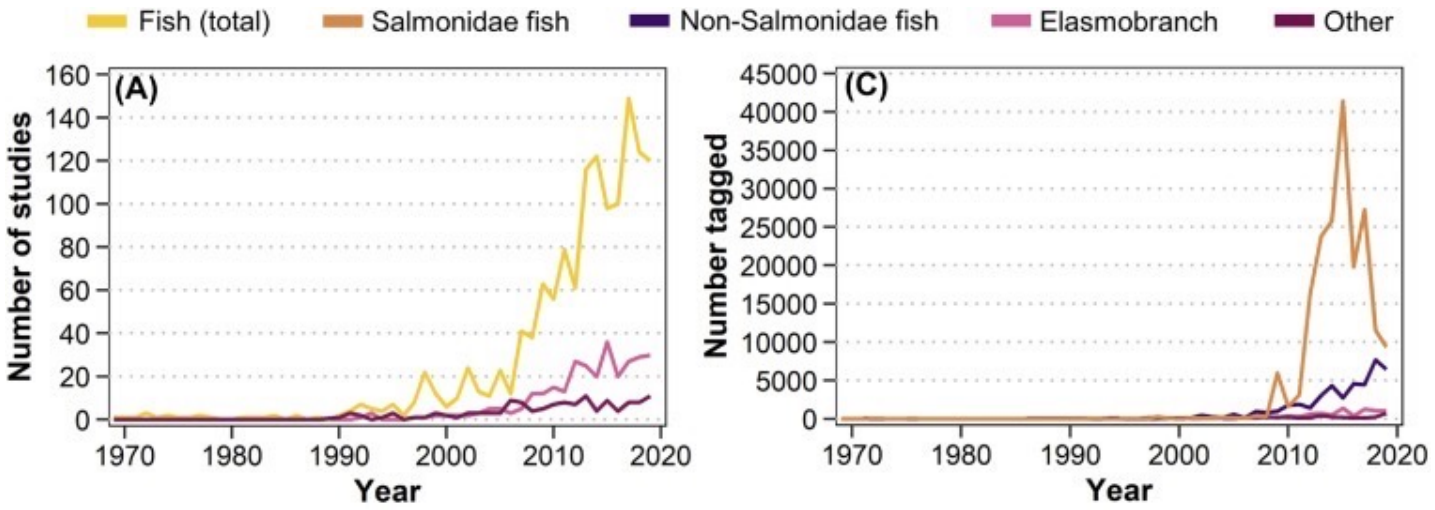
- Fisheries management
- MPA design
- Response of marine biodiversity to human impacts
- Habitat restoration



Alós et al., 2022. *Glob. Change Biol.*, 28: 5630-5653
https://doi.org/10.1111/gcb.16343

Acoustic Telemetry





REVIEW

ECOLOGY

Aquatic animal telemetry: A panoramic window into the underwater world

Nigel E. Hussey,[1] Steven T. Kessel,[1] Kim Aarestrup,[2] Steven J. Cooke,[3] Paul D. Cowley,[4] Aaron T. Fisk,[1] Robert G. Harcourt,[5] Kim N. Holland,[6] Sara J. Iverson,[7]* John F. Kocik,[8] Joanna E. Mills Flemming,[9] Fred G. Whoriskey[7]

Trends in Ecology & Evolution

CellPress OPEN ACCESS

Review

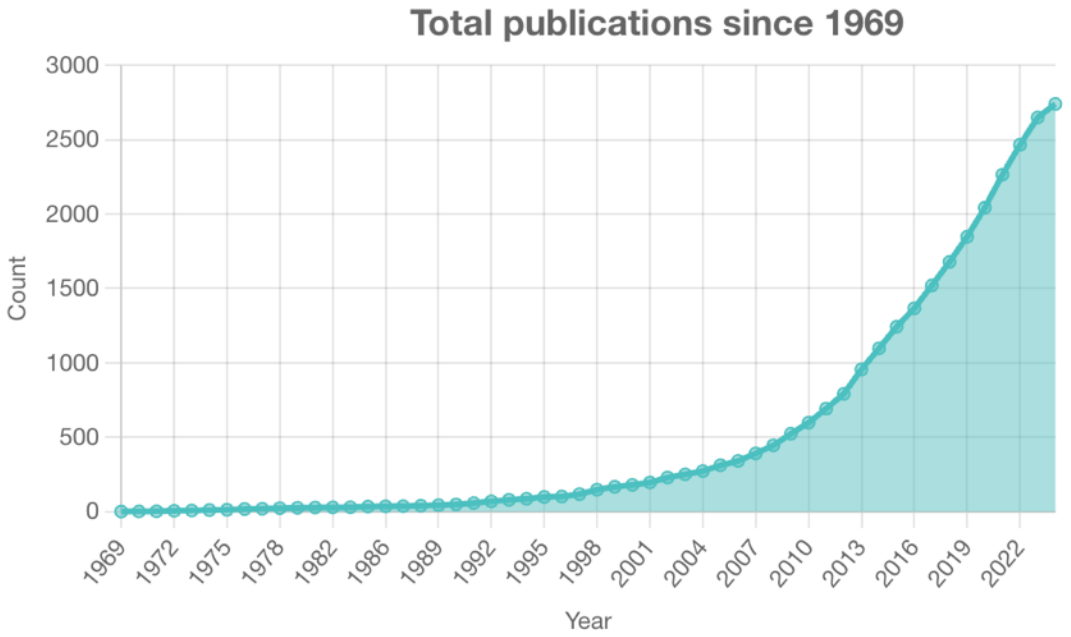
Global trends in aquatic animal tracking with acoustic telemetry

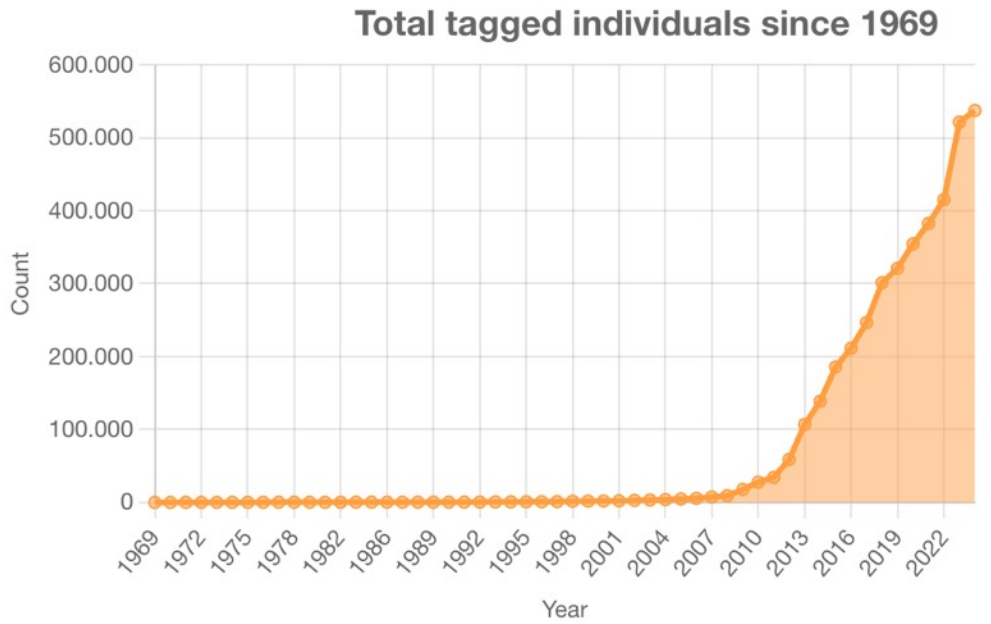
Jordan K. Matley, [1,18,19,*,@] Natalie V. Klinard, [2,19,*,@] Ana P. Barbosa Martins, [2,@] Kim Aarestrup, [3] Eneko Aspillaga, [4,@] Steven J. Cooke, [5,@] Paul D. Cowley, [6] Michelle R. Heupel, [7,@] Christopher G. Lowe, [8,@] Susan K. Lowerre-Barbieri, [9,10,@] Hiromichi Mitamura, [11] Jean-Sébastien Moore, [12,@] Colin A. Simpfendorfer, [13,@] Michael J.W. Stokesbury, [14,@] Matthew D. Taylor, [15] Eva B. Thorstad, [16,@] Christopher S. Vandergoot, [17,@] and Aaron T. Fisk [1,@]

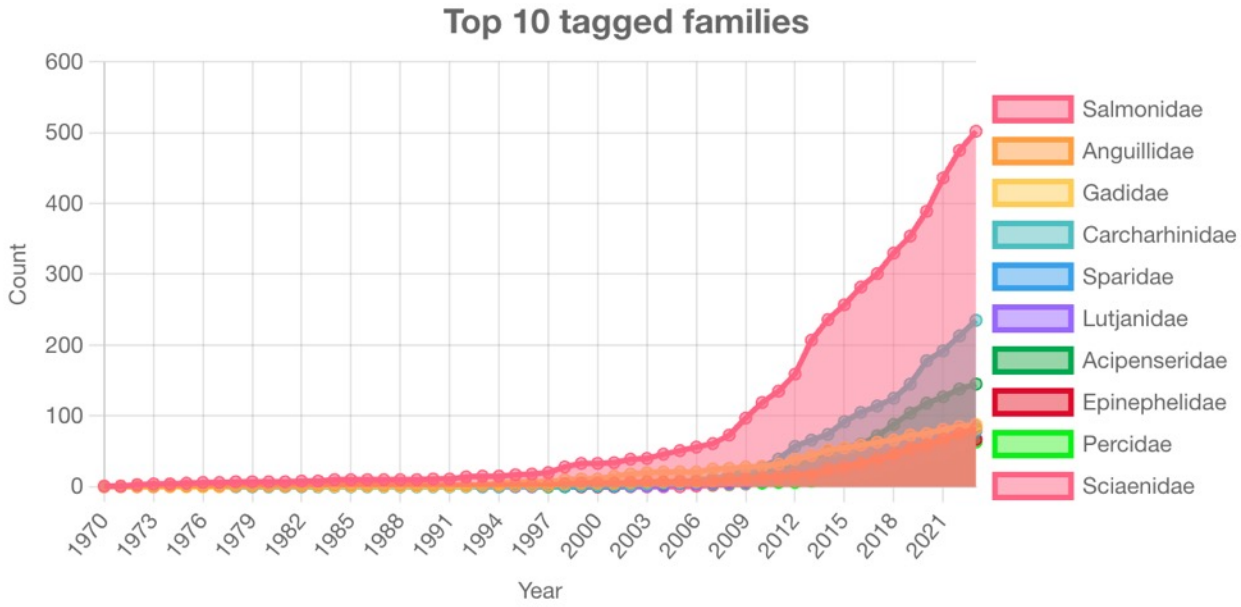
Hussey et al., 2015. *Science*, 348: 1255642
https://doi.org/10.1126/science.1255642
Matley et al., 2022. *Trends Ecol. Evo.*, *37*: 79-94
https://doi.org/10.1016/j.tree.2021.09.001

https://www.trackdat.org/

trackdAT

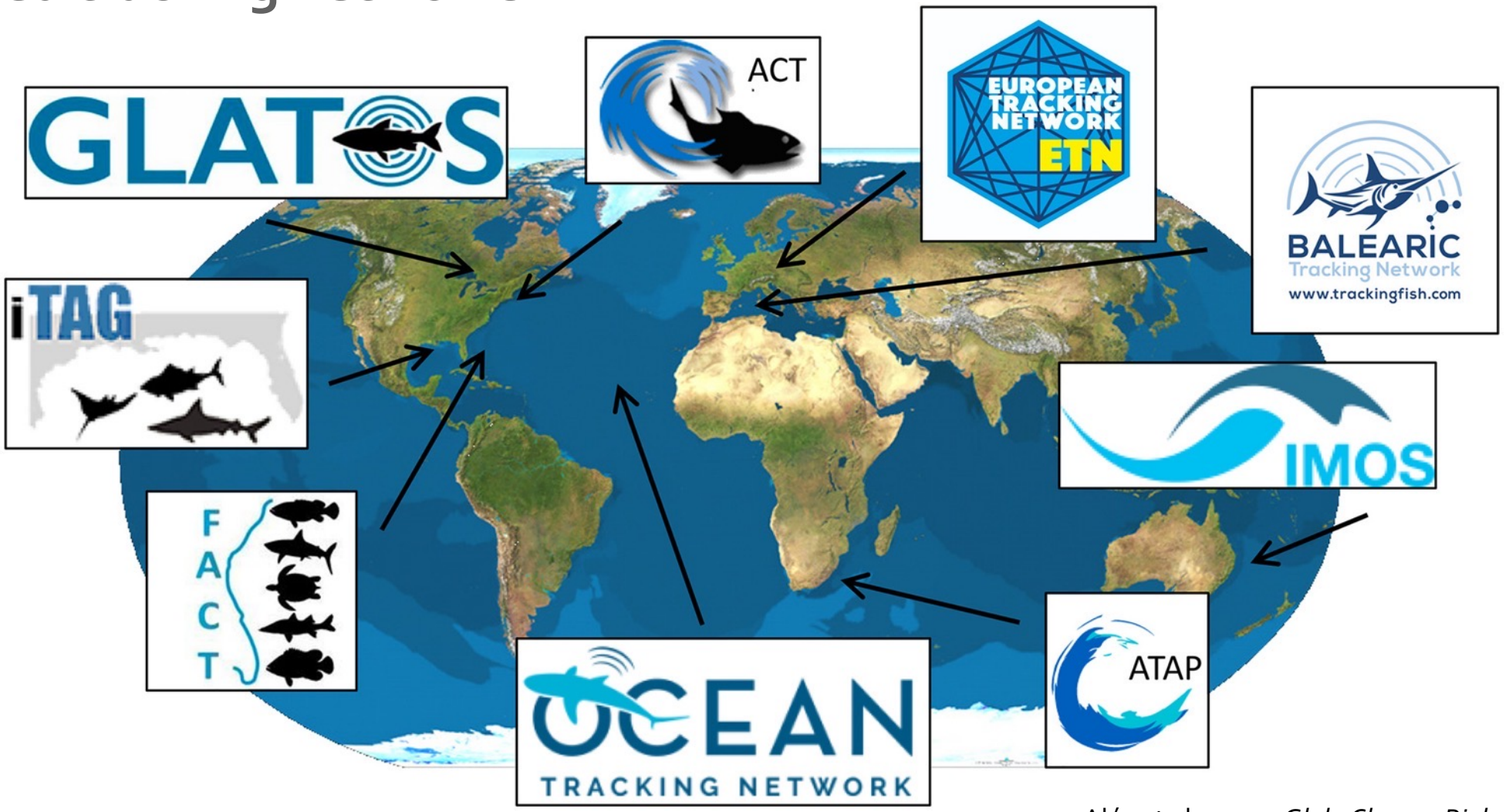






Matley et al., 2024. *Sci. Data*, *11*: 143
https://doi.org/10.1038/s41597-024-02969-y

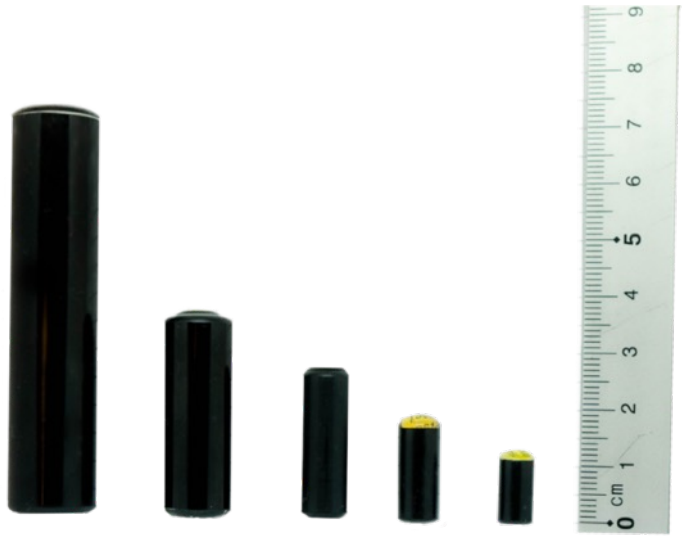
Integrated tracking networks



Alós et al., 2022. *Glob. Change Biol.*, 28: 5630-5653
https://doi.org/10.1111/gcb.16343

Basic concepts

Acoustic transmitters



TAG CHARACTERISTICS:

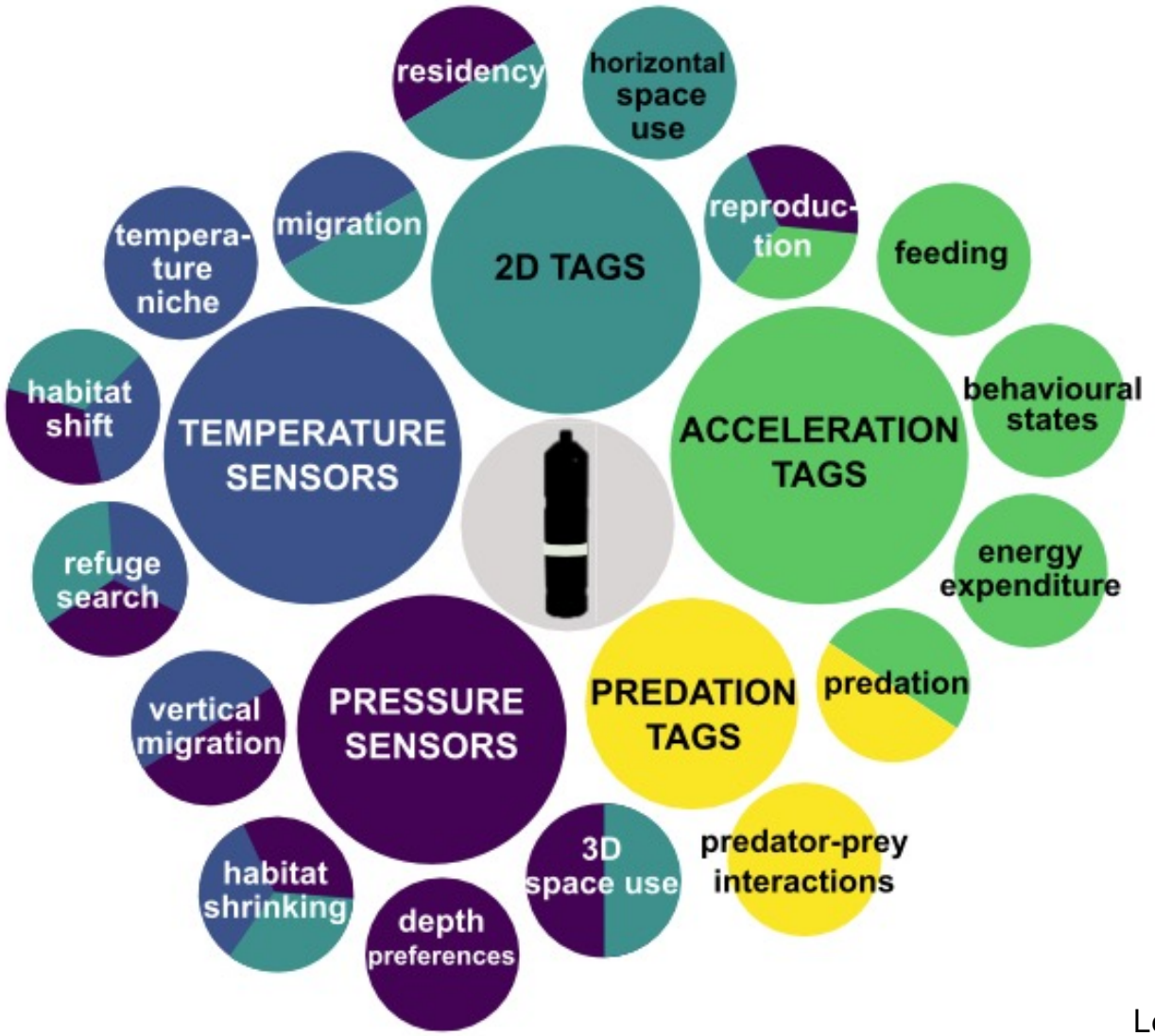
- Weight / size
- Transmission interval
- Transmit power (dB)
- Battery life
- Frequency (usually 69 kHz)
- Transmission protocol

SENSORS:

- Depth (pressure sensor)
- Temperature
- Activity (accelerometer)
- Tilt
- Conductivity
- Mortality

Source: Thelma Biotel
www.thelmabiotel.com

Sensor tags



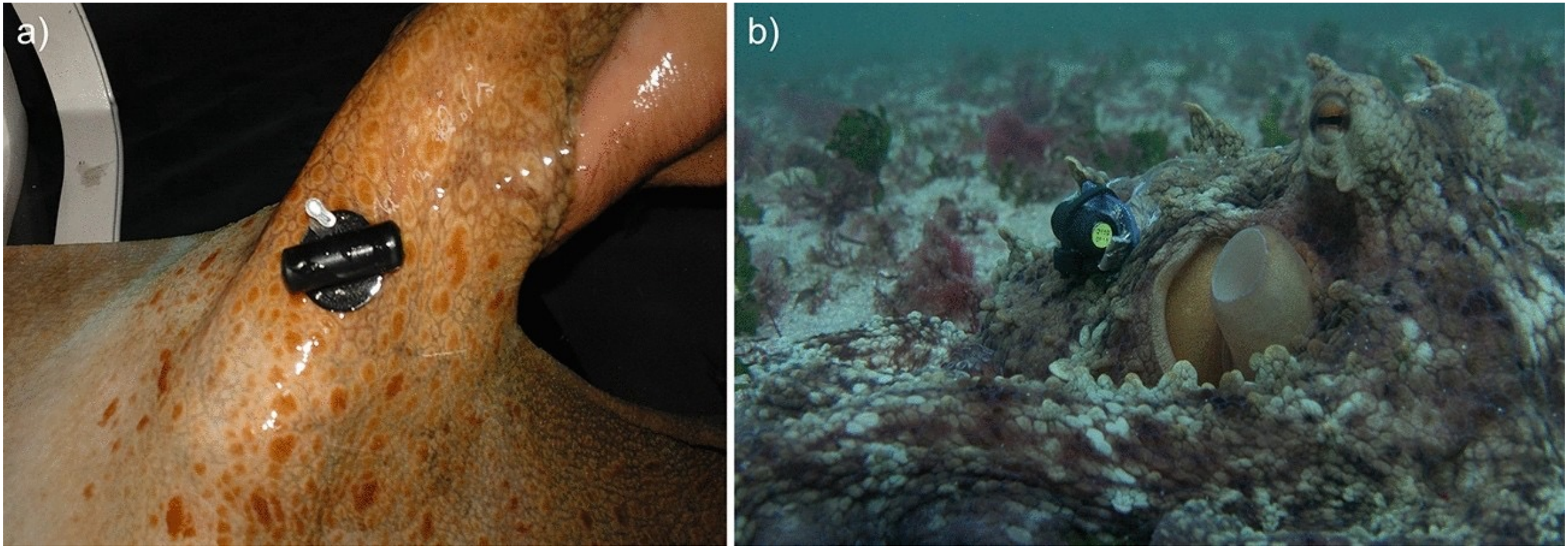
Lennox et al., 2024. CJFAS 81:326-339.
https://doi.org/10.1139/cjfas-2023-0145

Acoustic transmitters implantation


BALEARIC

Acoustic transmitters implantation

Acoustic transmitters implantation



Papadopoulo *et al.*, 2024. *Animal Biotelemetry* 12: 16
https://doi.org/10.1186/s40317-024-00361-6

Acoustic receivers

Fixed receivers

Acoustic release

Live receiver

RECEIVER CHARACTERISTICS:

- Battery life
- Frequency (no. of channels)
- Built-in sensors (temperature, noise, tilt)
- Built in transmitters (beacon signals)
- Transmission protocol*

INSTALLATION TYPE:

- Bottom mooring
- Buoys
- Release devices

Source: Thelma Biotel
www.thelmabiotel.com

RECEIVERS

TRANSMITTERS

TBR-800

WHS-6K

SUR

VR2W / VR2-AR
MAP-114 – MAP-115

ID-HPX / ID-LPX
OPi – OPs – R64K

MM-R-X
OPi – OPs

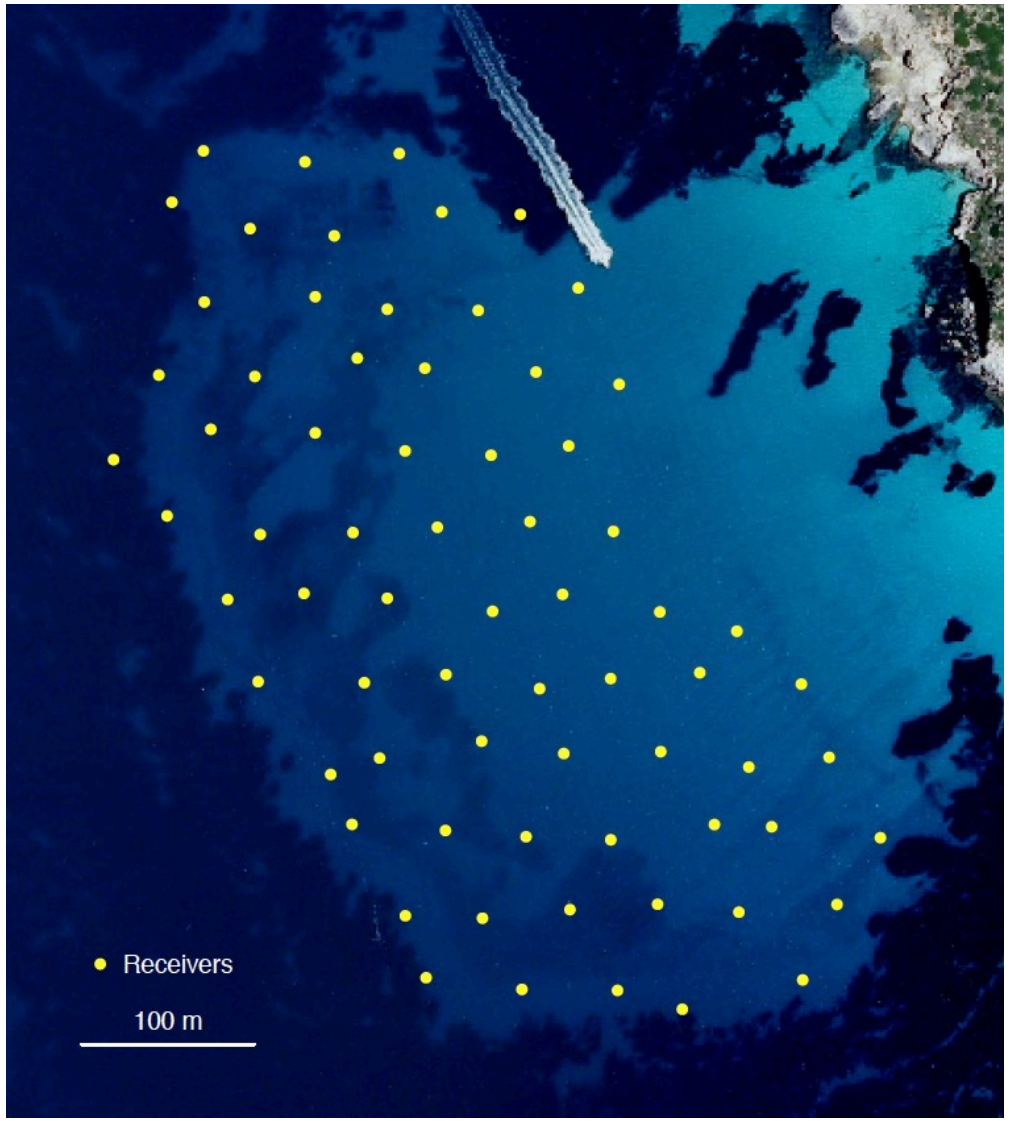
IBT/CT/CHP
OPi – OPs

V9-2x
A69-1602 – A69-9007

Image sources: www.thelmabiotel.com/; www.lotek.com/ ; www.sonotronics.com/ ; https://www.innovasea.com/

Acoustic receiver installation

Acoustic receiver arrays

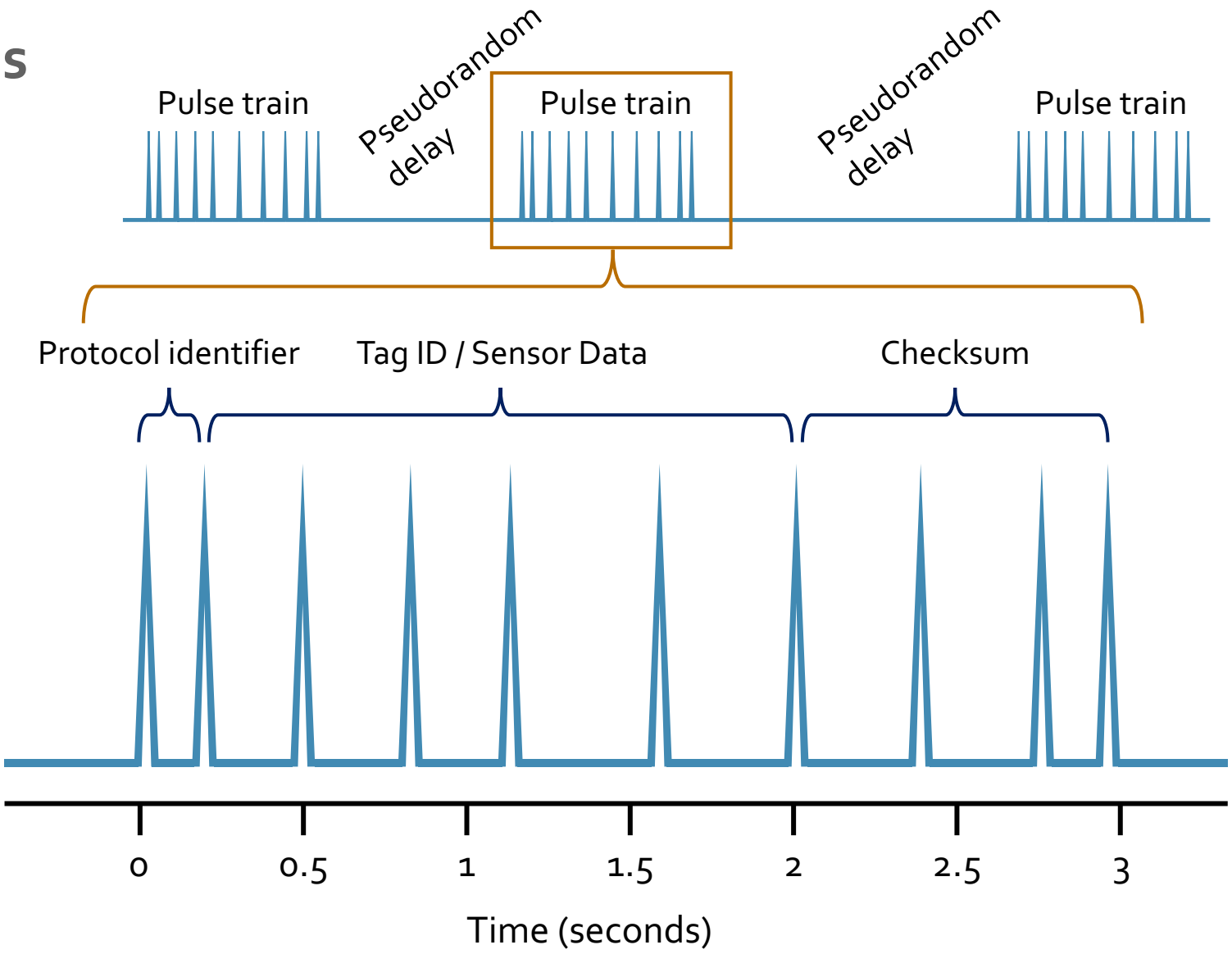


Signal emission systems

Signal transmission systems

Pulse Position Modulation (PPM)

- Most common transmission system
- Information is coded in the time between pulses
- Susceptible to tag collisions



Source: Lotek Wireless
www.lotek.com

Acoustic protocols

Manufacturers

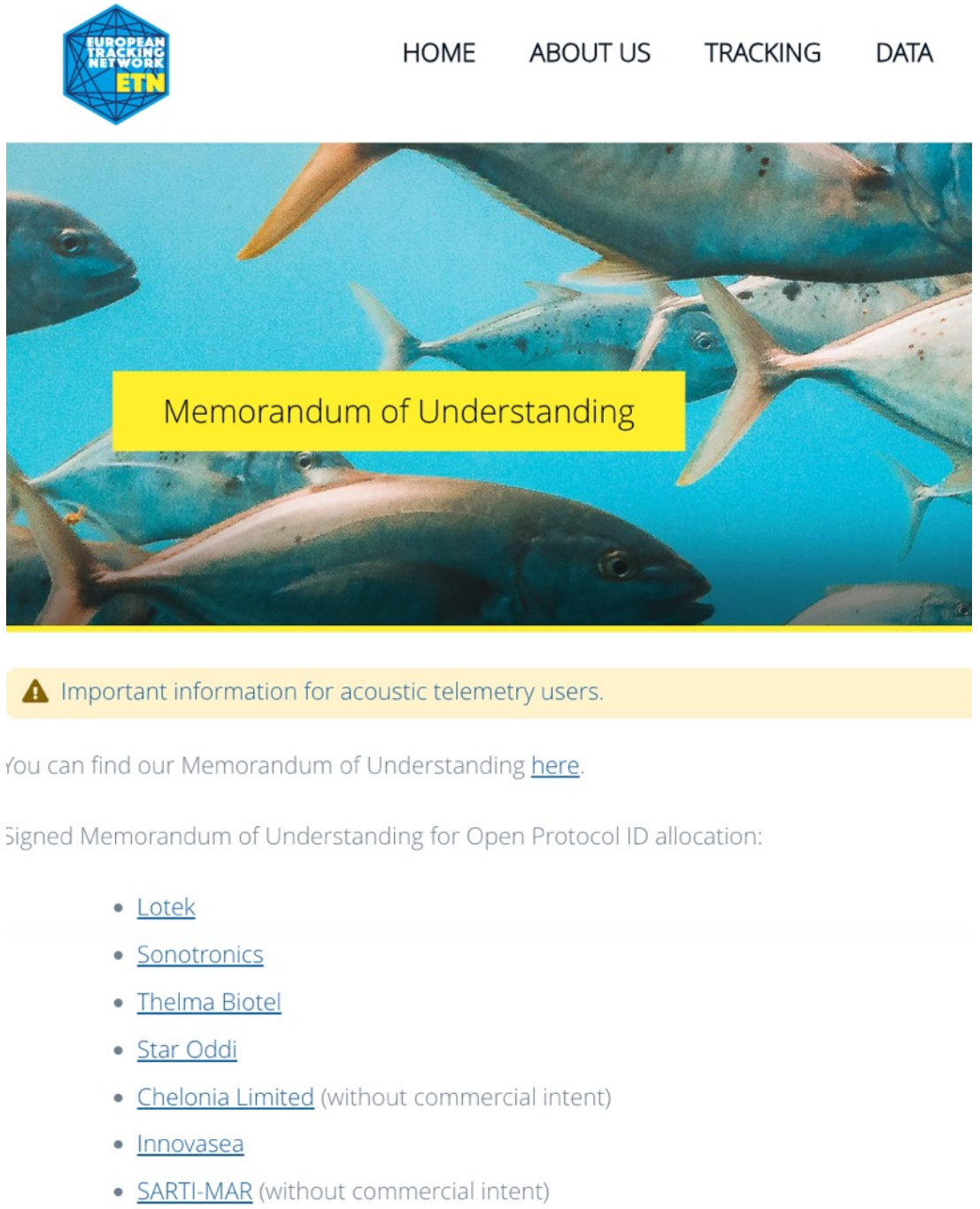
Protocols

	Thelma	Sonotronics	Lotek	Innovasea (Vemco)				
				MAP-110	MAP-112	MAP-113	MAP-114	MAP-115
OPi	+	+	+					
OPs	+	+	+					
R64K (A69-1303)	+	+	+	+	+	+	+	
S256 (A69-1105)	+	+	+	+	+	+		
R04K (A69-1206)	+	+		+	+			
R256 (A69-1008)	+			+				
H256	+							
DS256	+							
R01M	+							
S64K	+							
ACT		+						
MAP			+					
A69-9001, A69-9002, A69-9004					+	+	+	+
A69-9005					+			
A69-1601					+	+	+	+
A69-9006						+	+	+
A69-1602						+	+	+

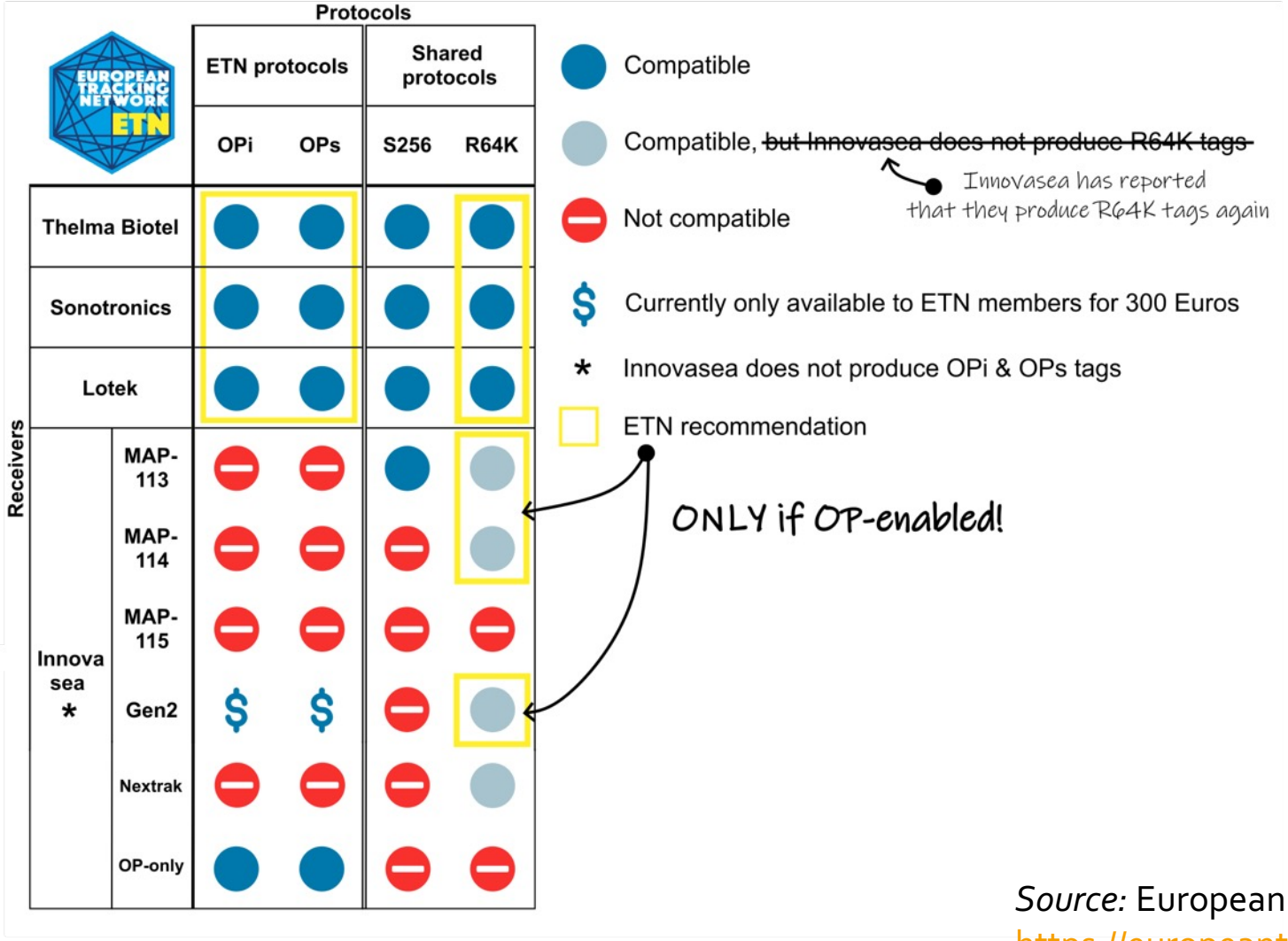
Open Protocols

Open Protocol

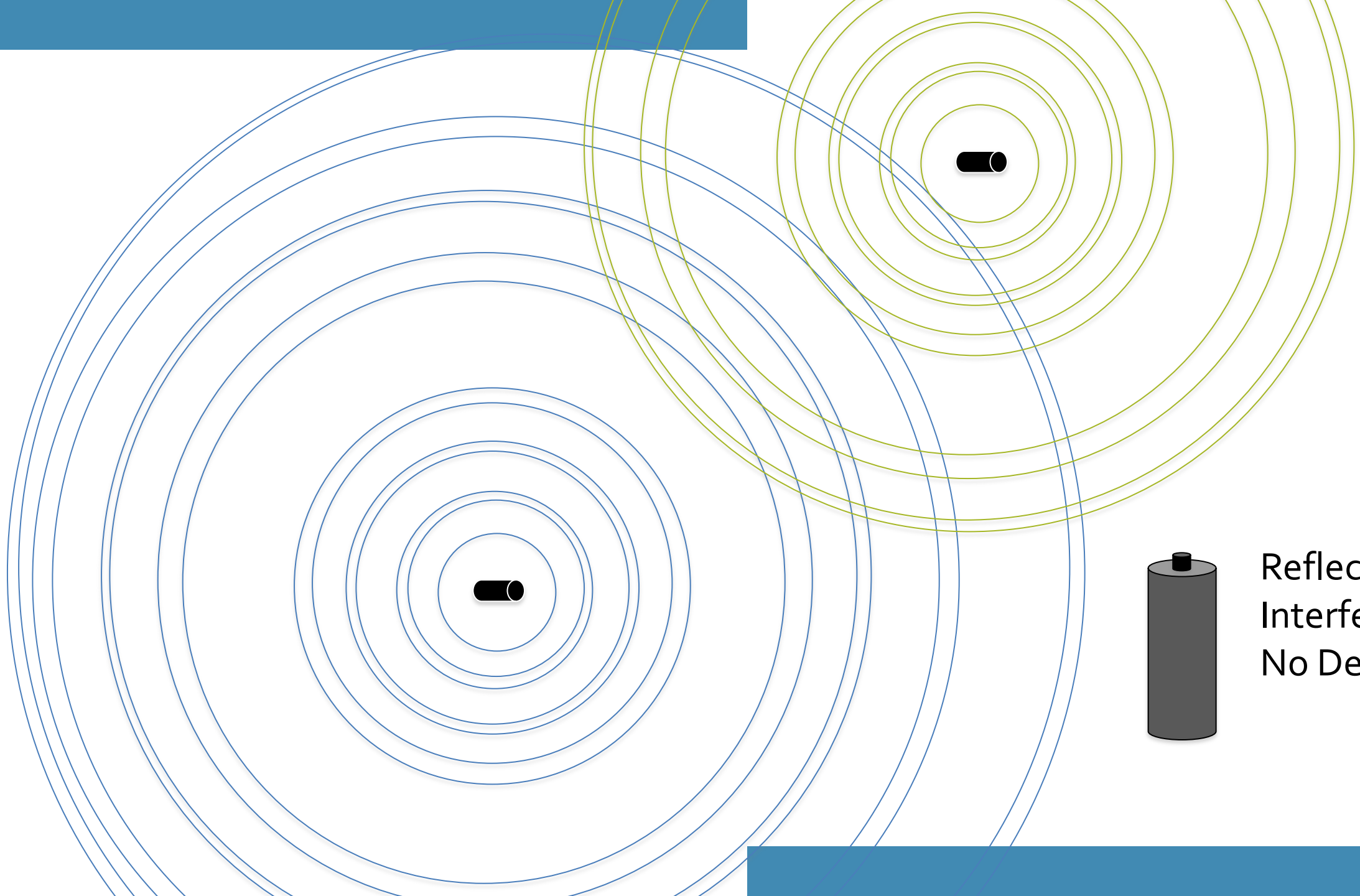
- Developed in 2020
- Available to all manufacturers accepting a license agreement
- Code allocation depends on a third party (VLIZ, Belgium)
- Two protocols:
  - OPi: ID tags
  - OPs: Sensor tags



Transmission protocols

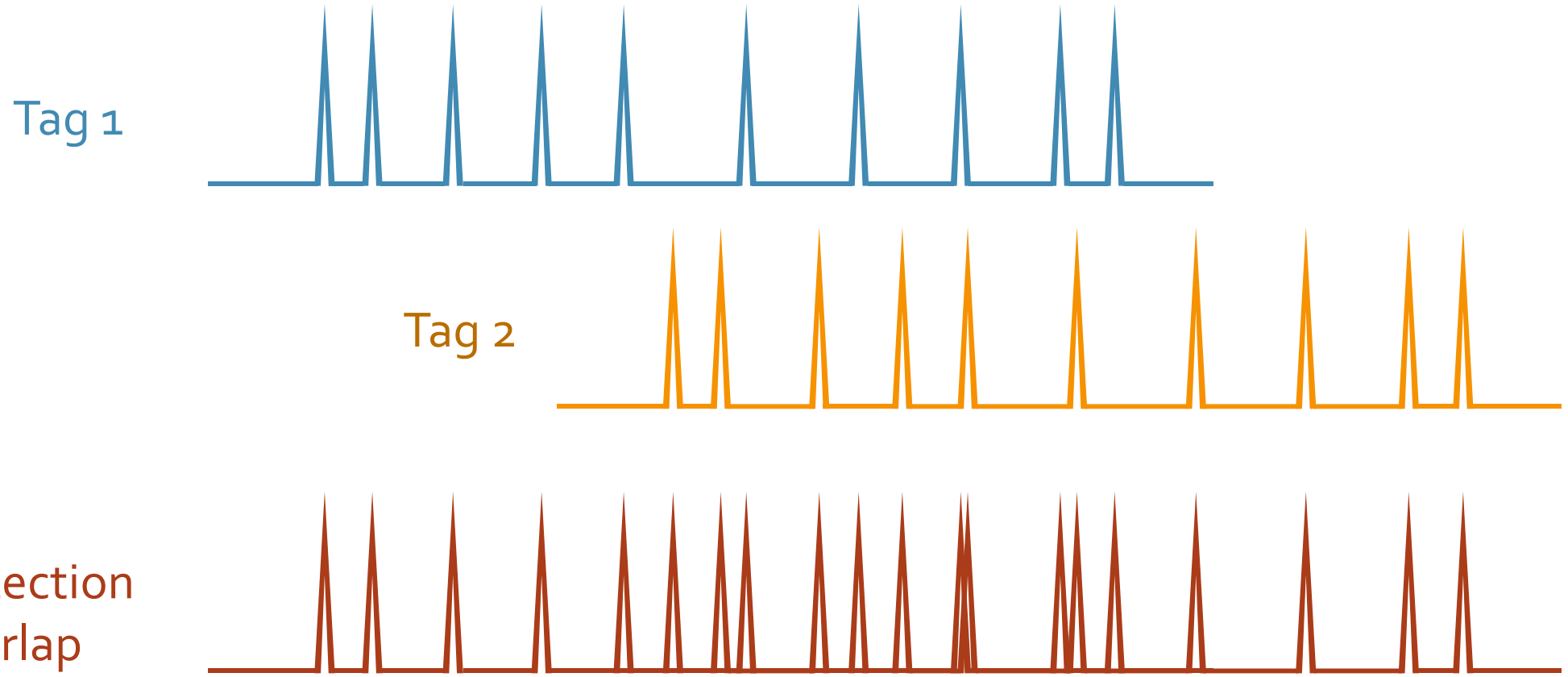


Source: European Tracking Network
https://europeantrackingnetwork.org



Reflection =
Interference =
No Detection!

Signal interference



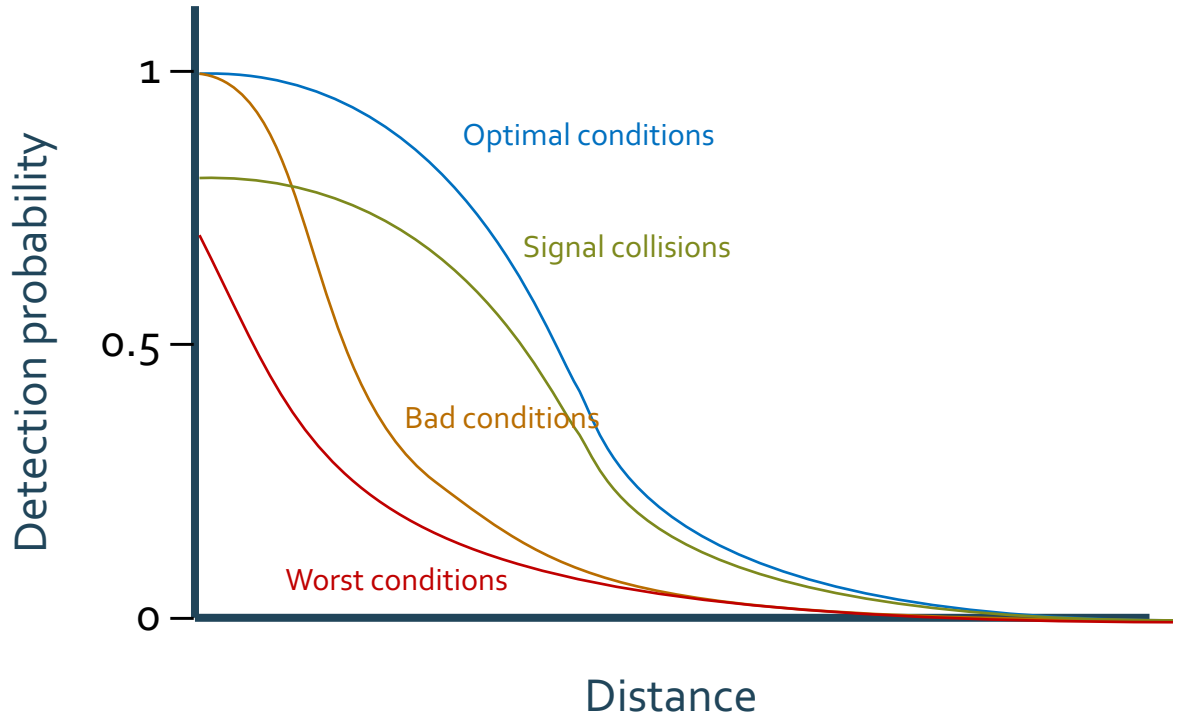
Cancelled signal (no detection)
False ID (wrong detection)

Detection probability

Affected by:

- Signal attenuation in water (distance)
- Water characteristics (temperature, salinity, thermoclines)
- Environmental noise (wind, waves, boats, biological noise)
- Signal reflexions (echoes)

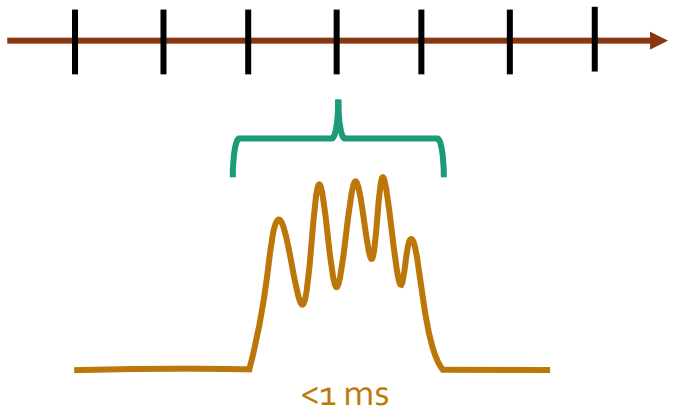
Importance of range testing!



Signal transmission systems

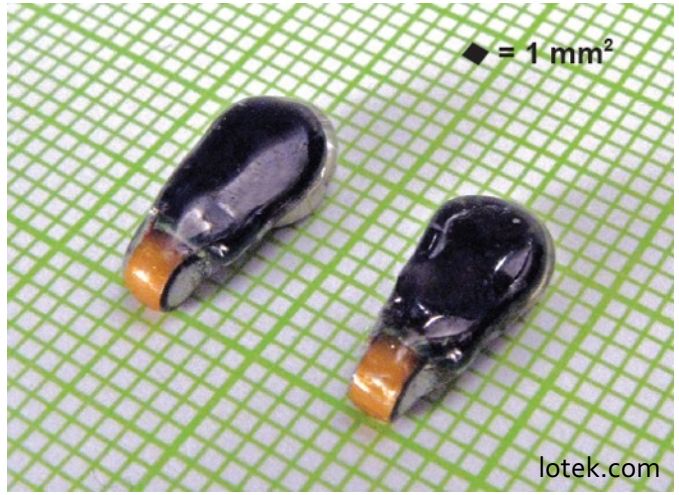
Binary Phase-Shift Keying (BPSK)

- Information is coded in signal modulation
- Faster signal transmission (< 1 ms)
- No collisions between signals
- Usually work at higher frequencies (e.g. 470 kHz)
- Less detection range



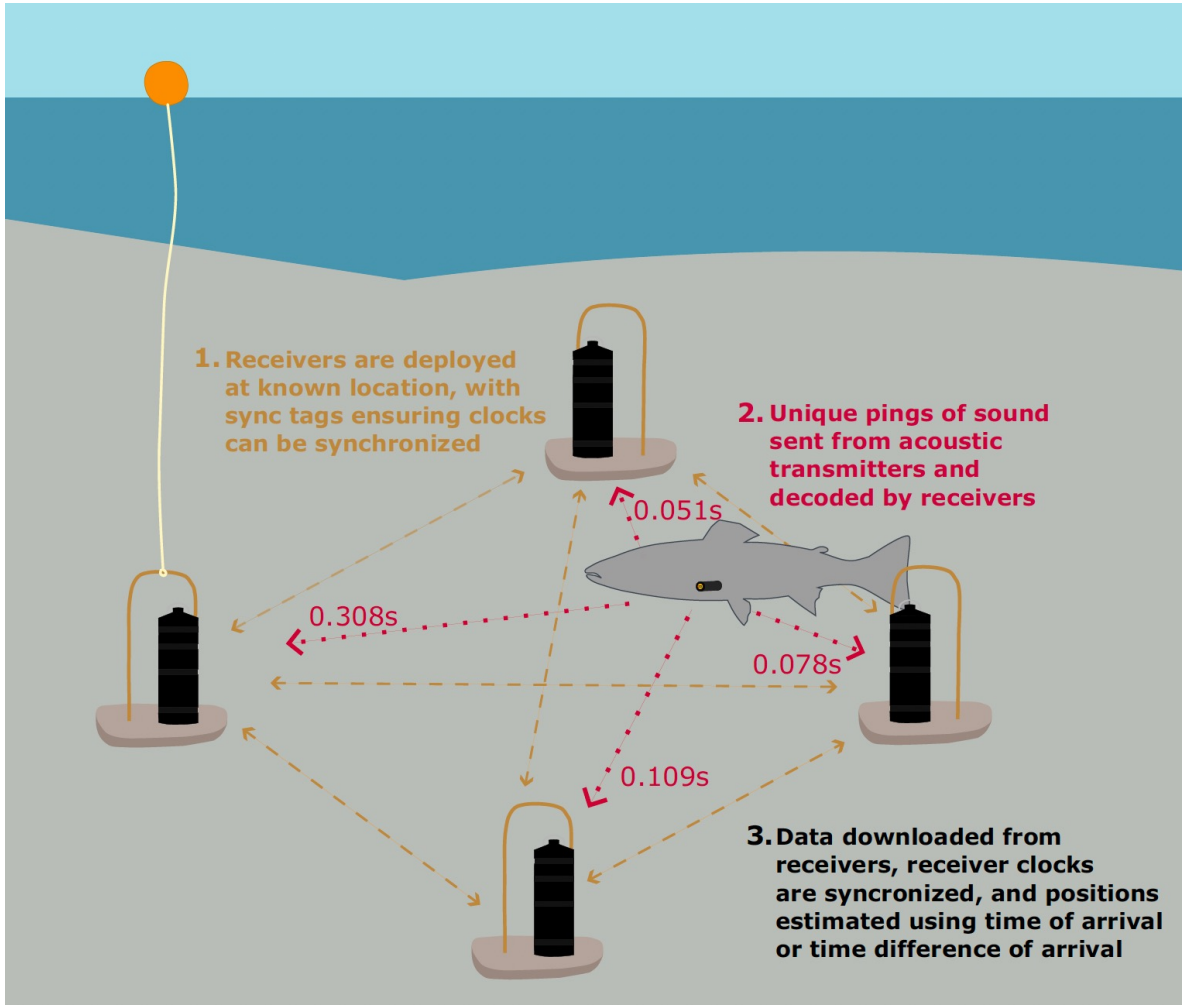
Simultaneous monitoring of 1000s of individuals

JSATS system



Source: Lotek Wireless
www.lotek.com

Positioning systems



Methods in Ecology and Evolution

REVIEW

Positioning aquatic animals with acoustic transmitters

Robert J. Lennox[1,2,3] | Kim Aarestrup[4] | Josep Alós[5] | Robert Arlinghaus[6,7] | Eneko Aspillaga[5] | Michael G. Bertram[8,9,10] | Kim Birnie-Gauvin[4] | Tomas Brodin[8] | Steven J. Cooke[11] | Lotte S. Dahlmo[1,12] | Félicie Dhellemmes[6] | Karl Ø. Gjelland[13]

Positioning method\service	Provider	Method? (e.g. TDOA, etc.)	Functions with less than three receivers overlapping?	Code available and transparent
Yet Another Positioning Solver (YAPS)	Open source	TOA	Yes	Yes
Vemco Positioning System (VPS)	Innovasea	TDOA	No	No
UMAP	Lotek	TDOA	No	No
Pinpoint	Thelma Biotel	TDOA	No	No

Time Difference of Arrival (TDOA)
Hyperbolic multilateration)
Detections in >= 3 receivers

Time of Arrival (TOA)
Track-based approach
Robust to suboptimal receiver array configuration

Lennox *et al.*, 2024. *Methods Ecol. Evo.*, 14:2514-2530.
https://doi.org/10.1111/2041-210X.14191

Acoustic telemetry databases

How to structure an acoustic telemetry database

- Three main data sources:

Deployment log (receivers)

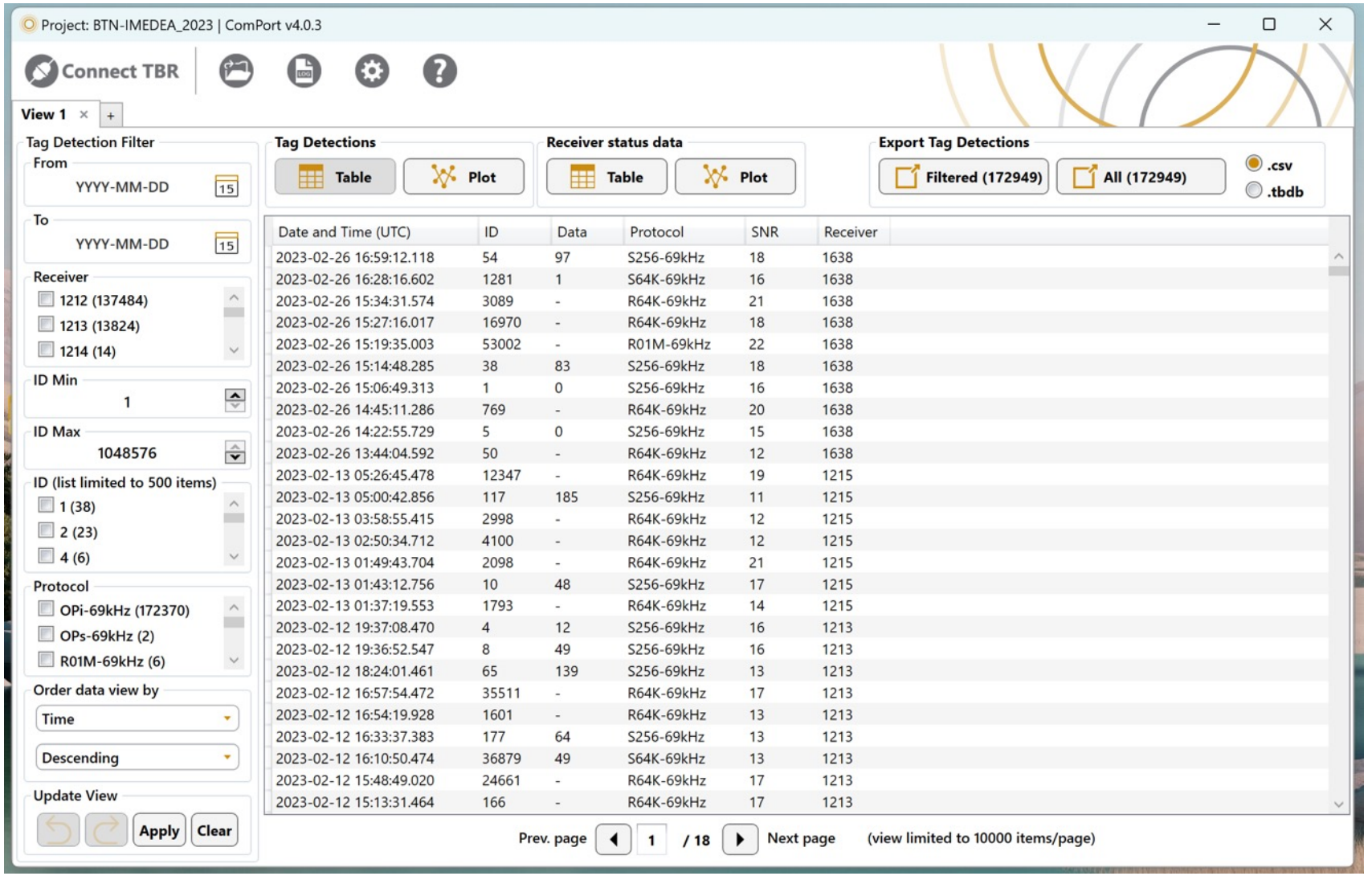
Fish and metadata (tagged fish)

Receiver log files (detection data)

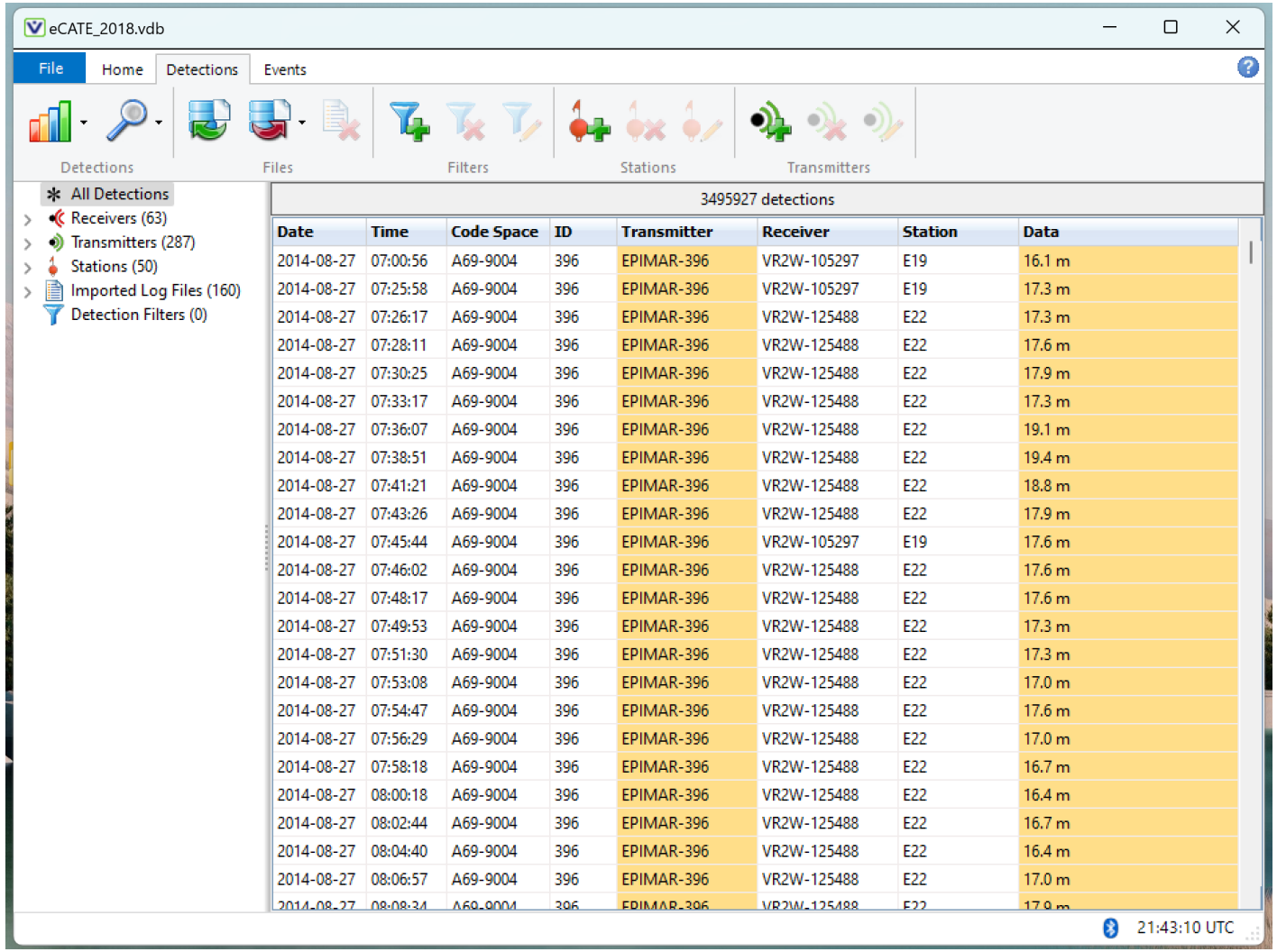
Structure of receiver log files

THELMABIOTEL

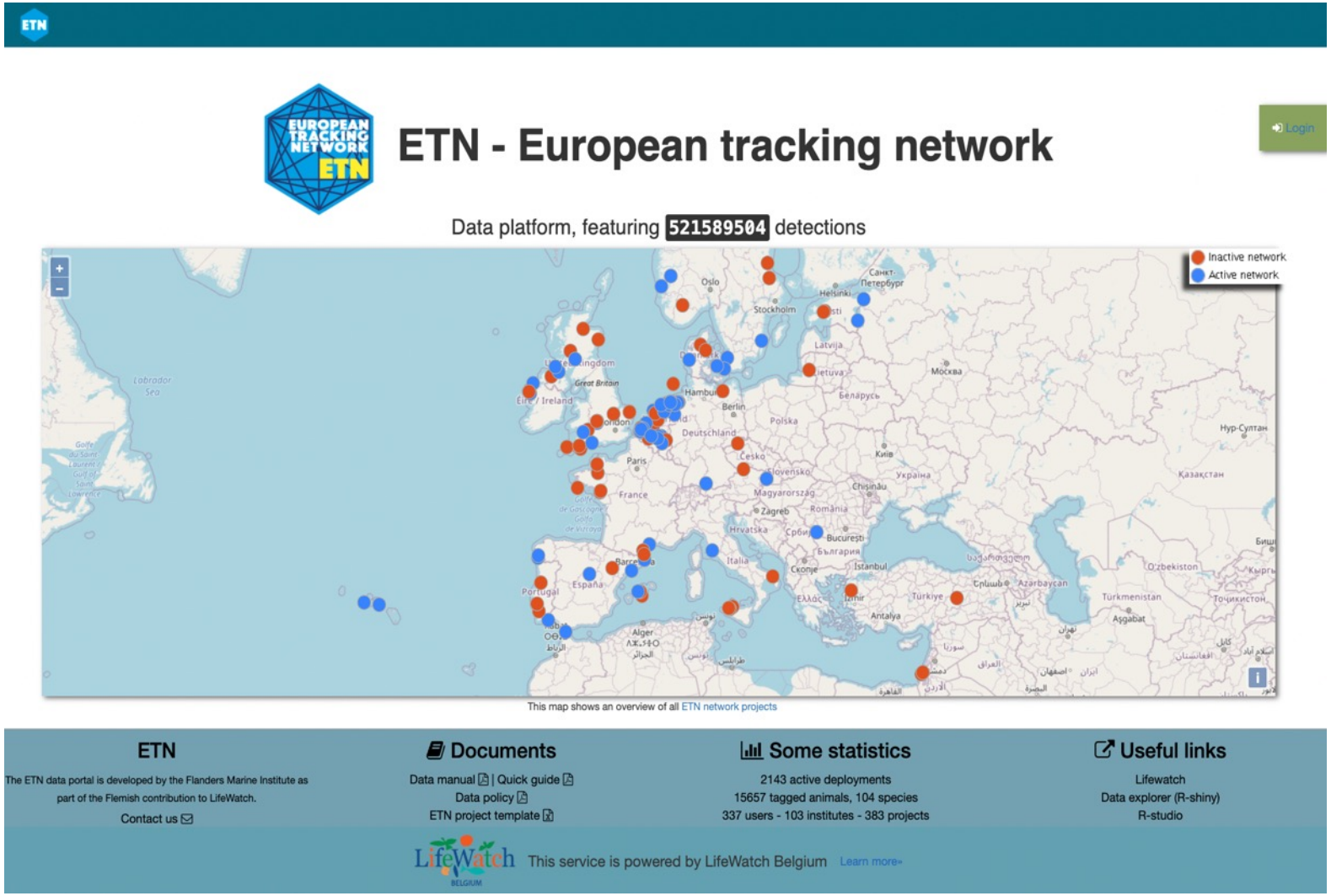
ComPort



Structure of receiver log files



Online data platforms

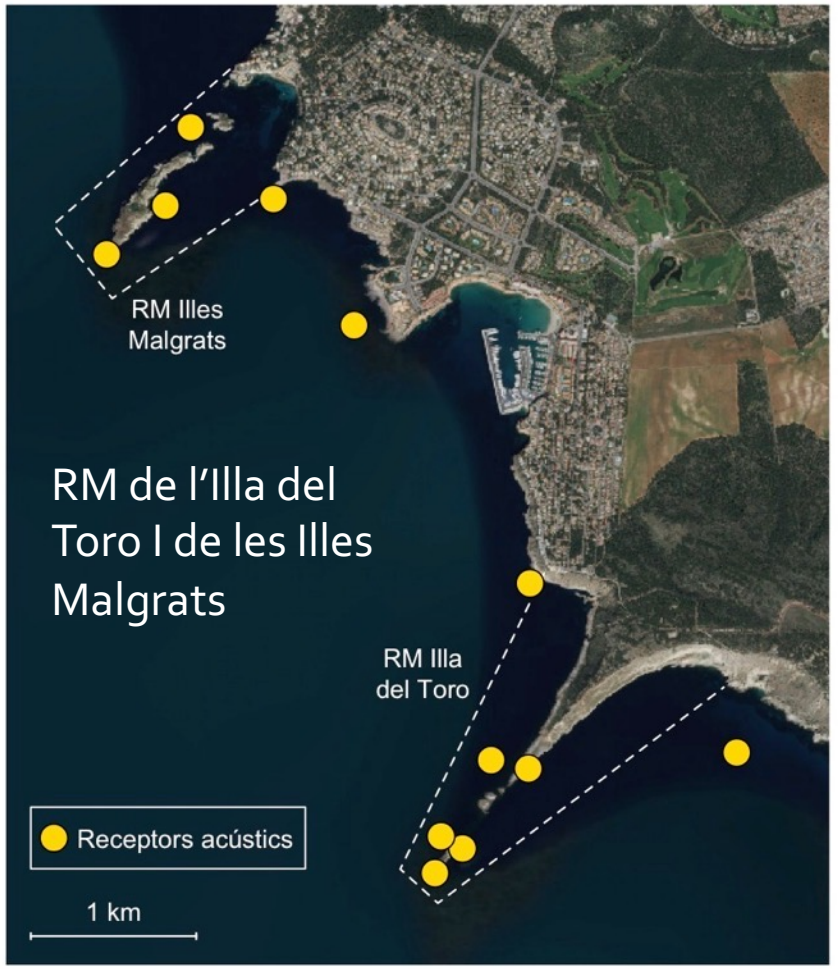


Examples of applications

Dusky grouper (*Epinephelus marginatus*)

Long-term residence and movement patterns

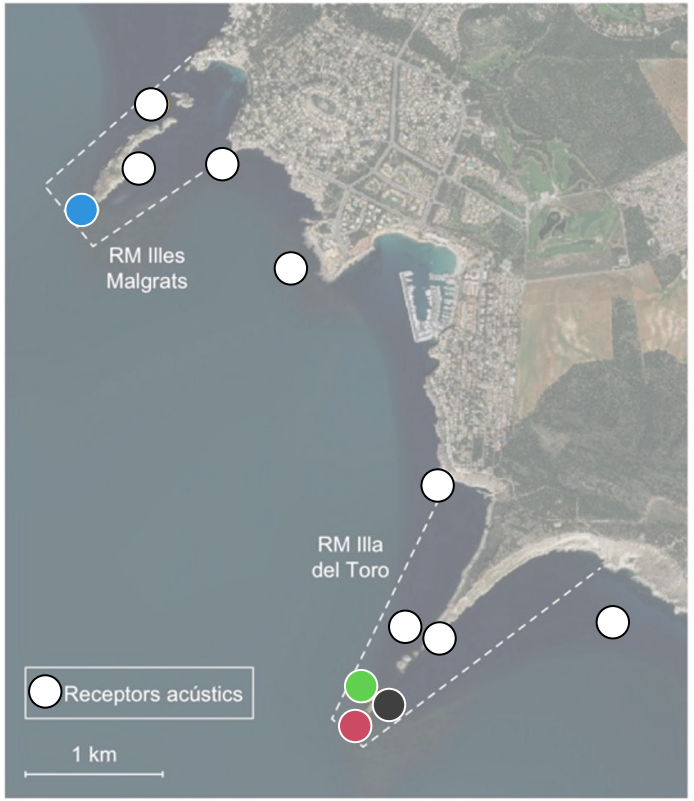
Tag model: MM-R-16 (LotelWireless Inc.)
Open Protocol
Emission period: 2 min
Battery life: >11 yr



Dusky grouper (*Epinephelus marginatus*)

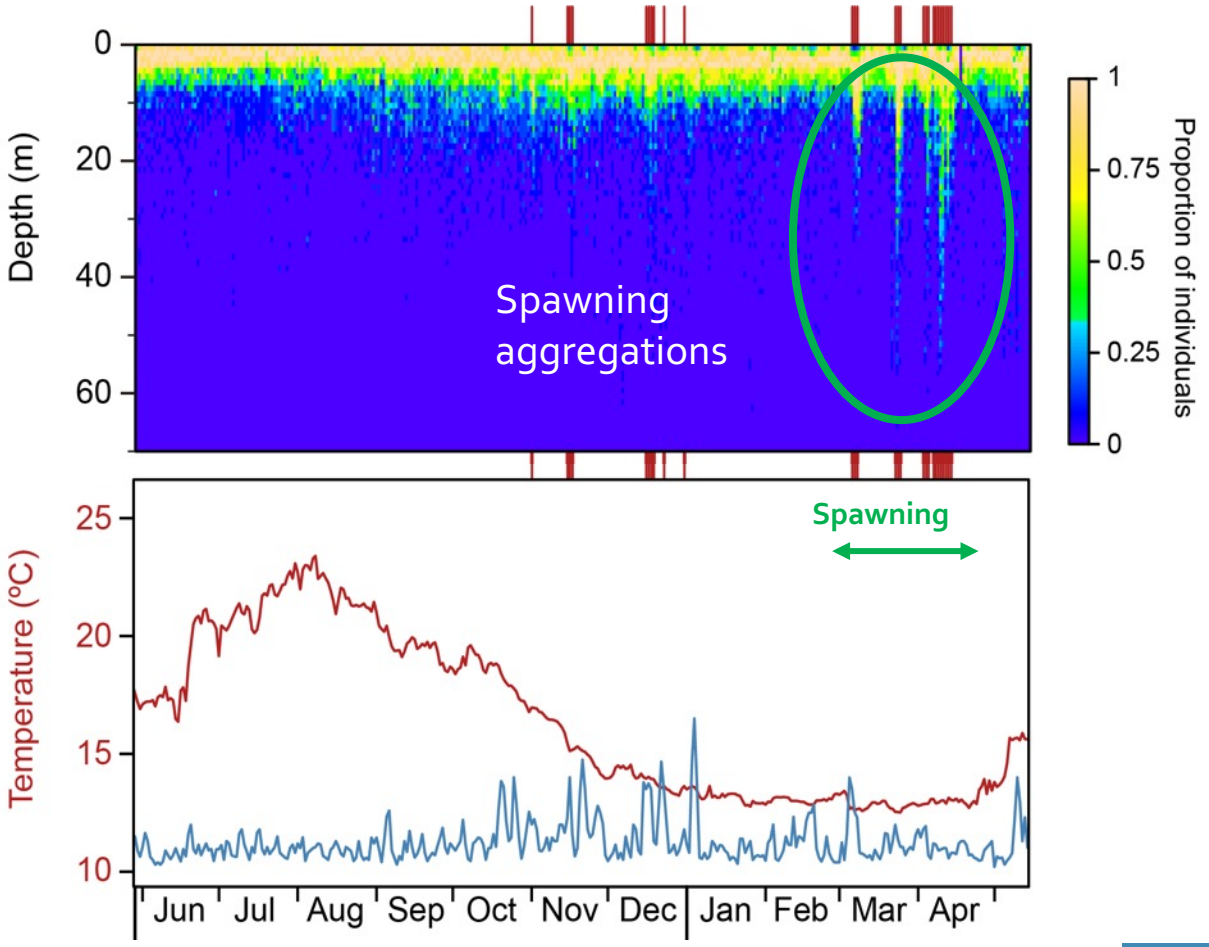
Long-term residence and movement patterns

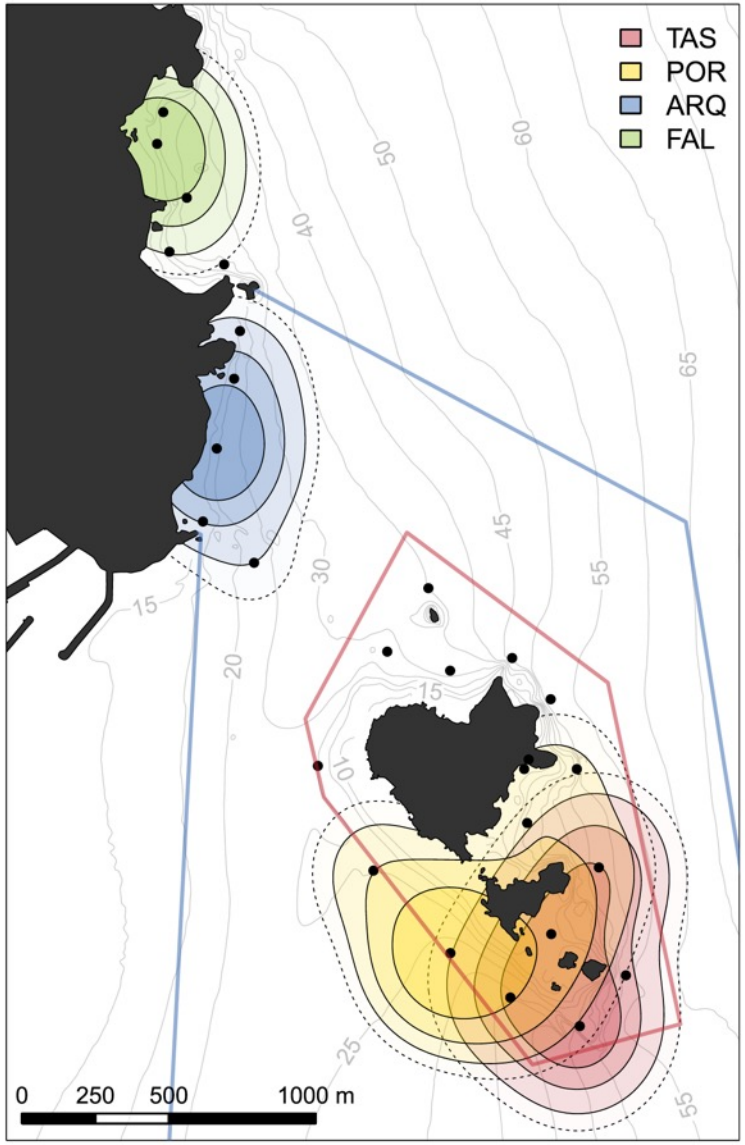
Length: 52–87 cm



Home-range analysis

White seabream (*Diplodus sargus*)



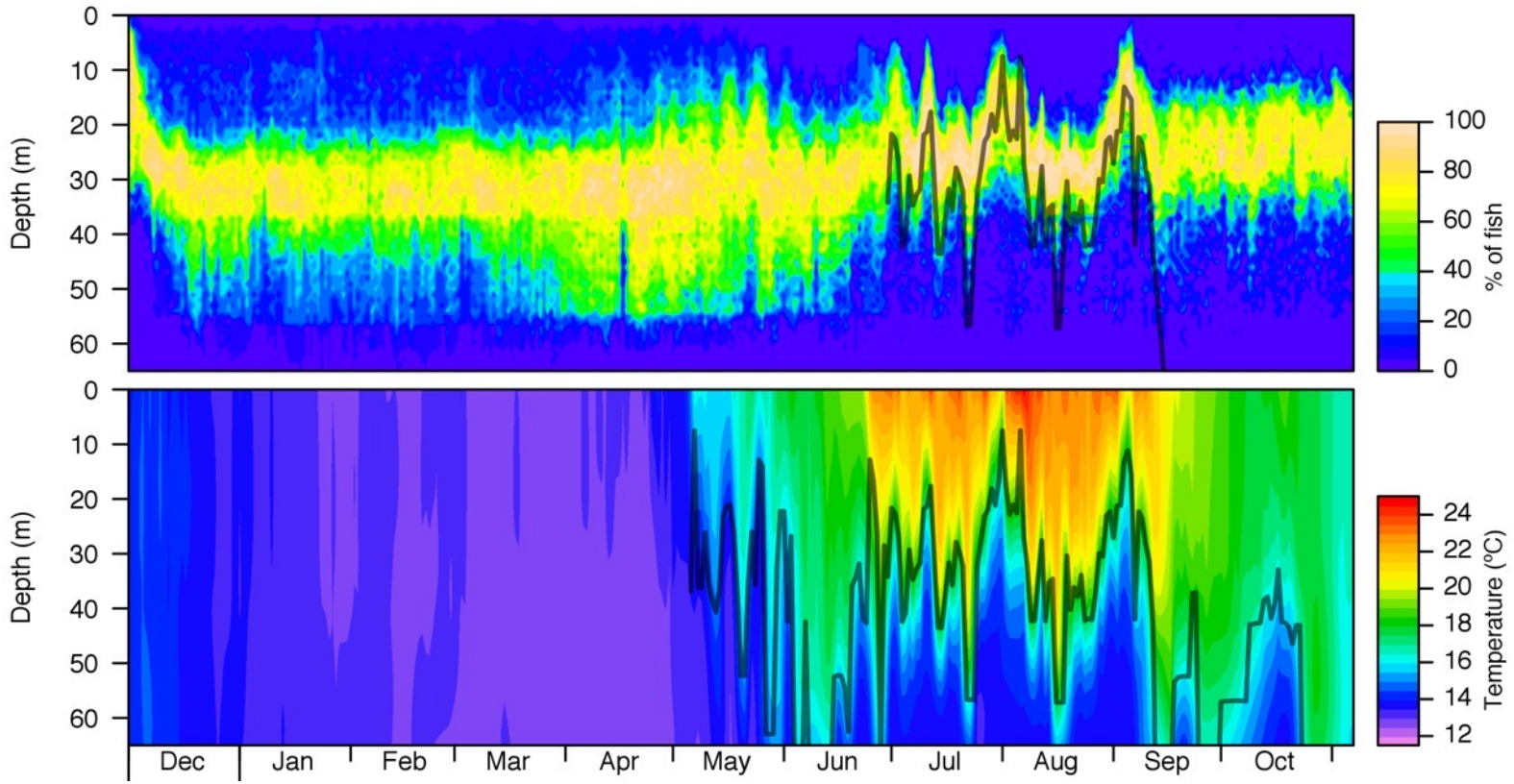


Aspillaga *et al.*, 2016. *PLoS ONE.*, 11(7): e0159813. https://doi.org/10.1371/journal.pone.0159813

Effect of environmental variables

Common dentex (*Dentex dentex*)

Effect of water stratification (thermocline) on vertical distribution and activity patterns



Aspillaga *et al.*, 2017. *Sci. Rep.*, *7*: 526
https://doi.org/10.1038/s41598-017-00576-z

MPA connectivity

BALEARIC Tracking Network
www.trackingfish.com

- *Epinephelus marginatus*
- *Dentex dentex*
- *Seriola dumerili*
- *Dasyatis pastinaca*
- *Gymnura altavela*
- *Sphyraena viridensis*

14 km

COREMAR

Avaluació de la **connectivitat** de la xarxa de **reserves marines** de les Illes Balears

Conselleria d'Economia, Hisenda i Innovació
Direcció General de Recerca, Innovació i Transformació Digital

GOBIERNO DE ESPAÑA

Pla de Recuperació, Transformació i Resiliència

Finançat per la Unió Europea
NextGenerationEU

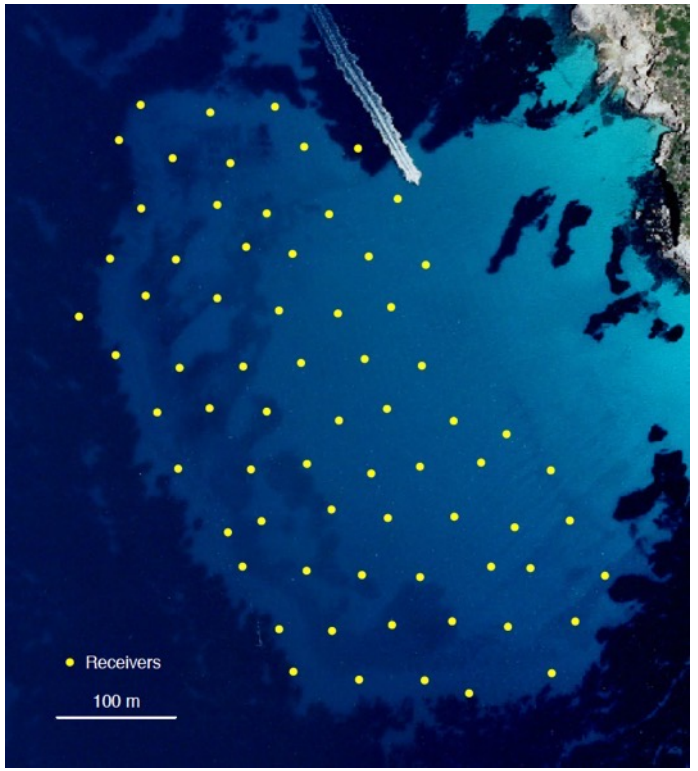
High-resolution acoustic telemetry

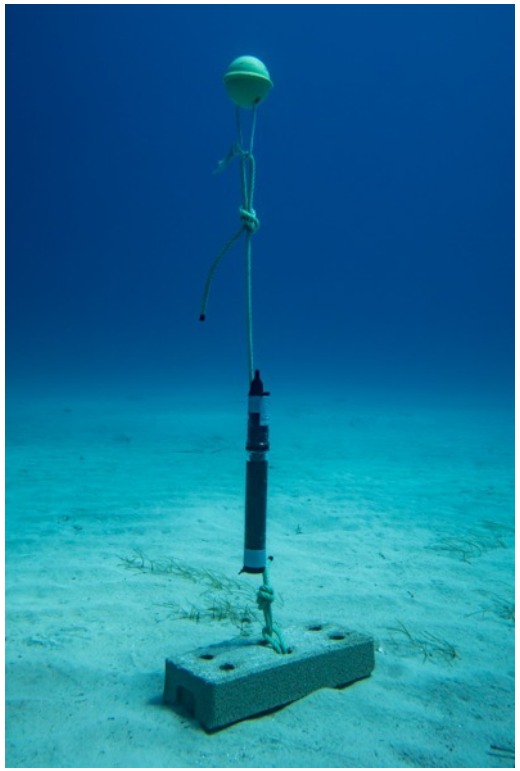
Tagged with **L-AMT series transmitters** (Lotek):

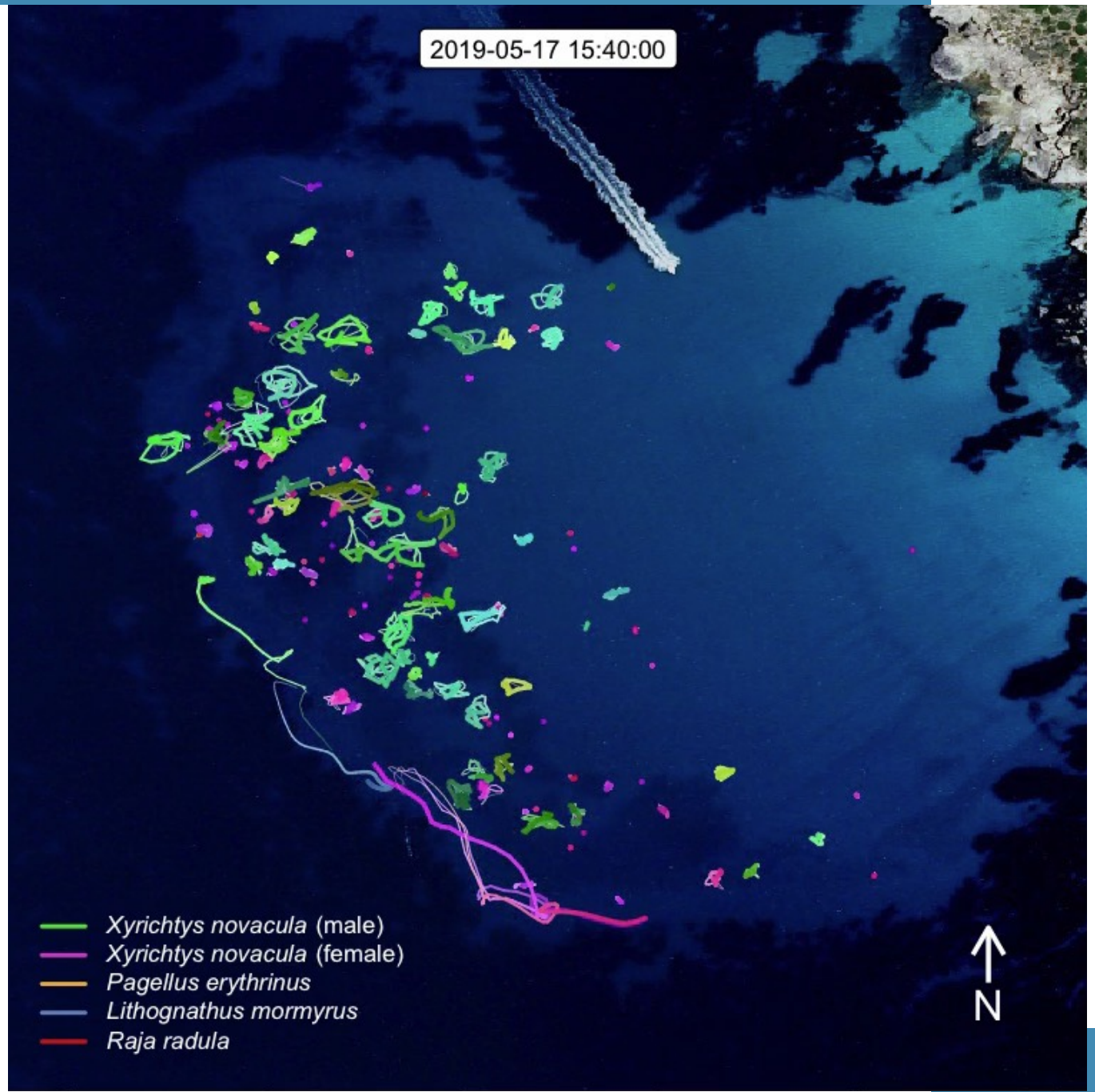
Transmission period = 2–10 s
Freq: 416.70 kHz
Dry weight: 0.32–3.5 g

Pearly razorfish (*Xyrichtys novacula*)

320 individuals:
195 females (9–18 cm)
125 males (13–22 cm)







Aspillaga *et al. Anim Biotelemetry* (2021) 9:1
https://doi.org/10.1186/s40317-020-00224-w

Animal Biotelemetry

METHODOLOGY Open Access

Performance of a novel system for high-resolution tracking of marine fish societies

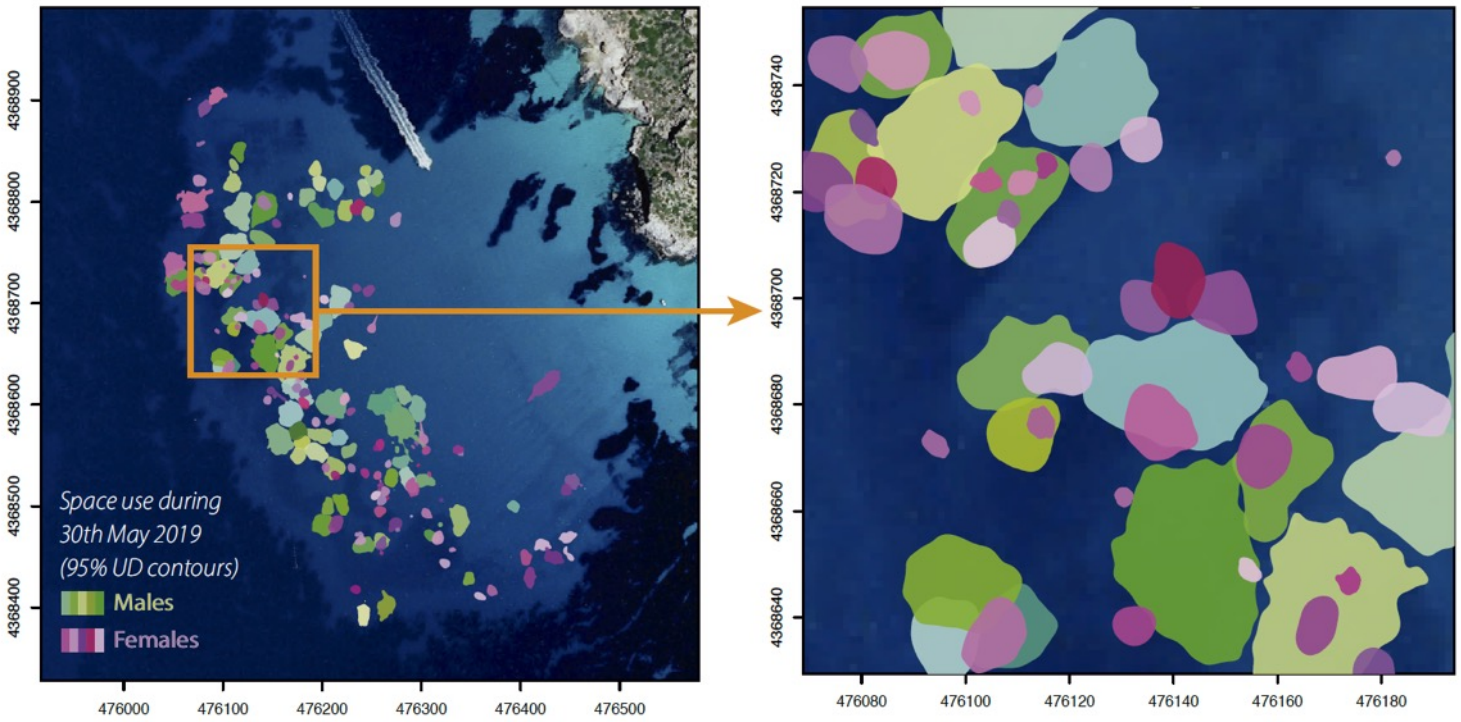
Eneko Aspillaga[1*], Robert Arlinghaus[2,3], Martina Martorell-Barceló[1], Guillermo Follana-Berná[1,4], Arancha Lana[1], Andrea Campos-Candela[1,2] and Josep Alós[1]

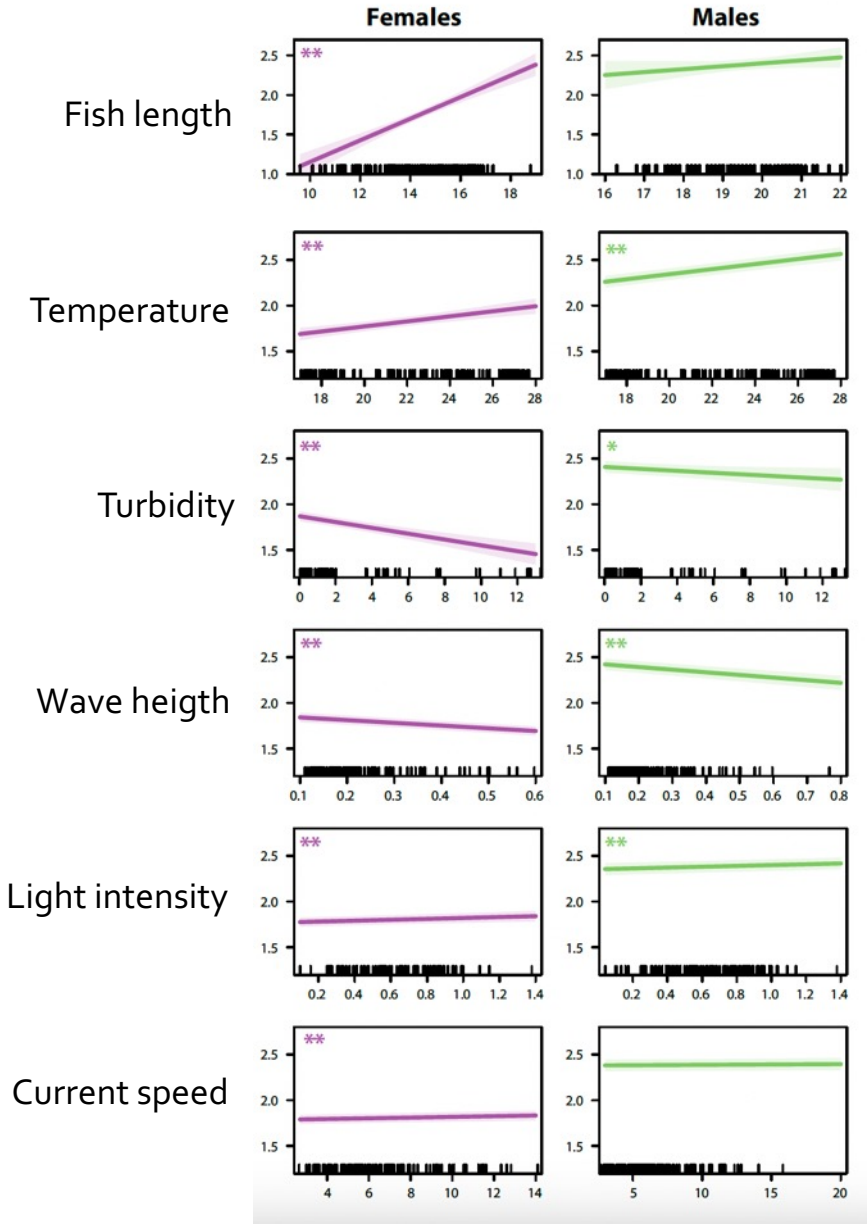
$3.6 \cdot 10^8$ detections
$4.2 \cdot 10^7$ raw positions

Photo credit: Martina Martorell

Aspillaga *et al.*, 2021. *Anim. Biotel*, 9: 1
https://doi.org/10.1186/s40317-020-00224-w

Space-use patterns





Territorial behavior

Average space use / day:

Females: 88.5 ± 82.2 m²

Males: 326.1 ± 211.2 m²

Jordi Abad's MSc Thesis (2022)

Social Network Analysis

frontiers in Marine Science

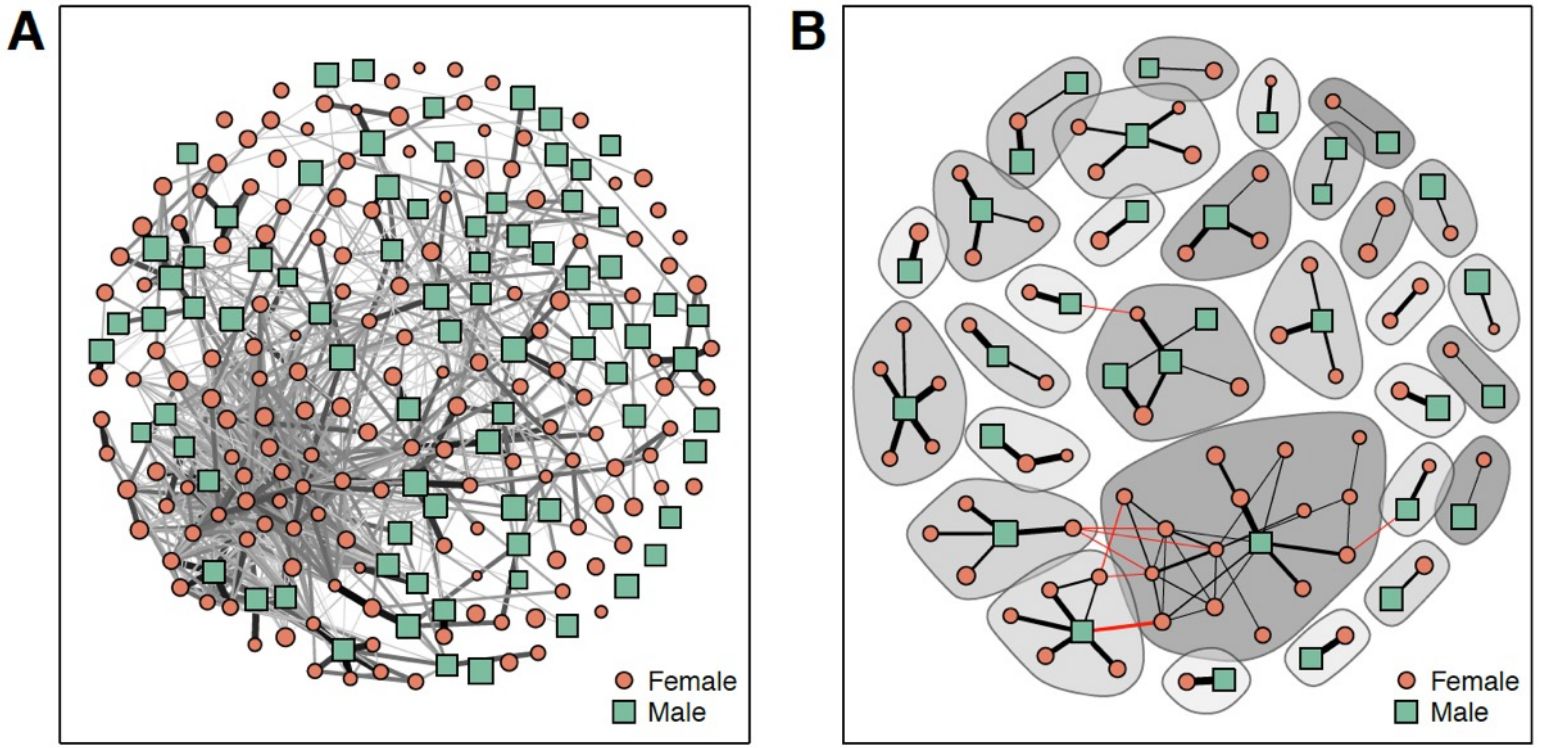
High-Throughput Tracking of Social Networks in Marine Fish Populations

Eneko Aspillaga[1], Robert Arlinghaus[2,3], Martina Martorell-Barceló[1], Margarida Barcelo-Serra[1] and Josep Alós[1]*

Low interactions between individual of the same sex

Harem structure (1 male, several females)

Punctual aggregations of females



Aspillaga *et al.*, 2021. Front. Mar. Sci. 8:688010
DOI: https://doi.org/10.3389/fmars.2021.688010

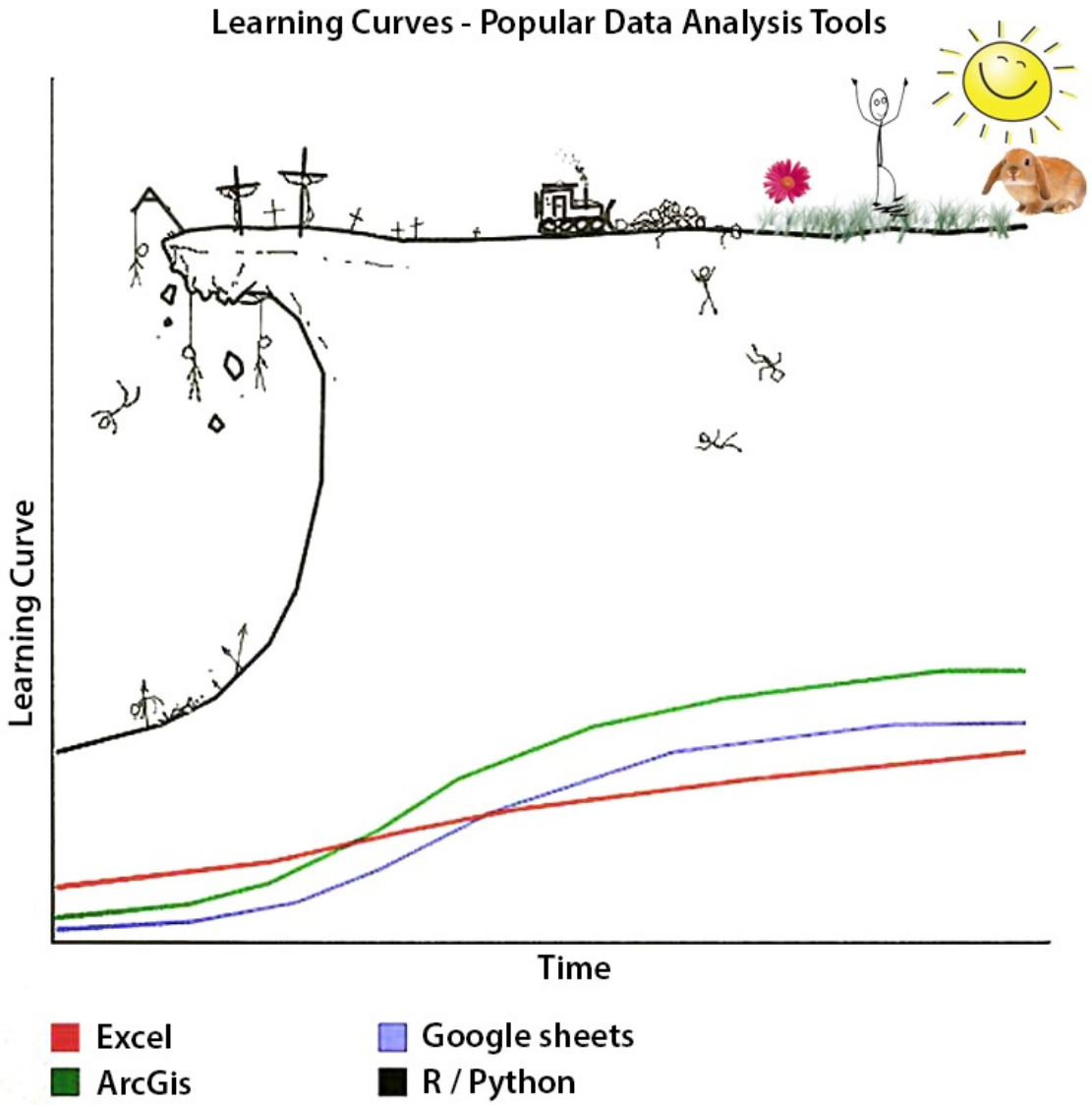
Practical session in R

Why to embrace R

- Open-source
- Platform-independent
- Lots of packages and an active developer community
- **Reproducibility and sharing**
- High **performance** and **versatility** in data handling and analysis
  - Statistical analysis, spatial analysis (GIS), data visualizations

But…

- Steep learning curve?



Source: https://nceas.github.io/oss-lessons/spatial-data-gis-law/1-mon-spatial-data-intro.html

Practical examples

- Example R scripts:

  `MASS_01_Loading_and_merging_AT_data.R`

  `MASS_02_Analyzing_AT_data.R`