

# Introduction to acoustic telemetry for tracking fish

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<https://github.com/aspillaga>  
@enekoasp



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

# Acoustic Telemetry

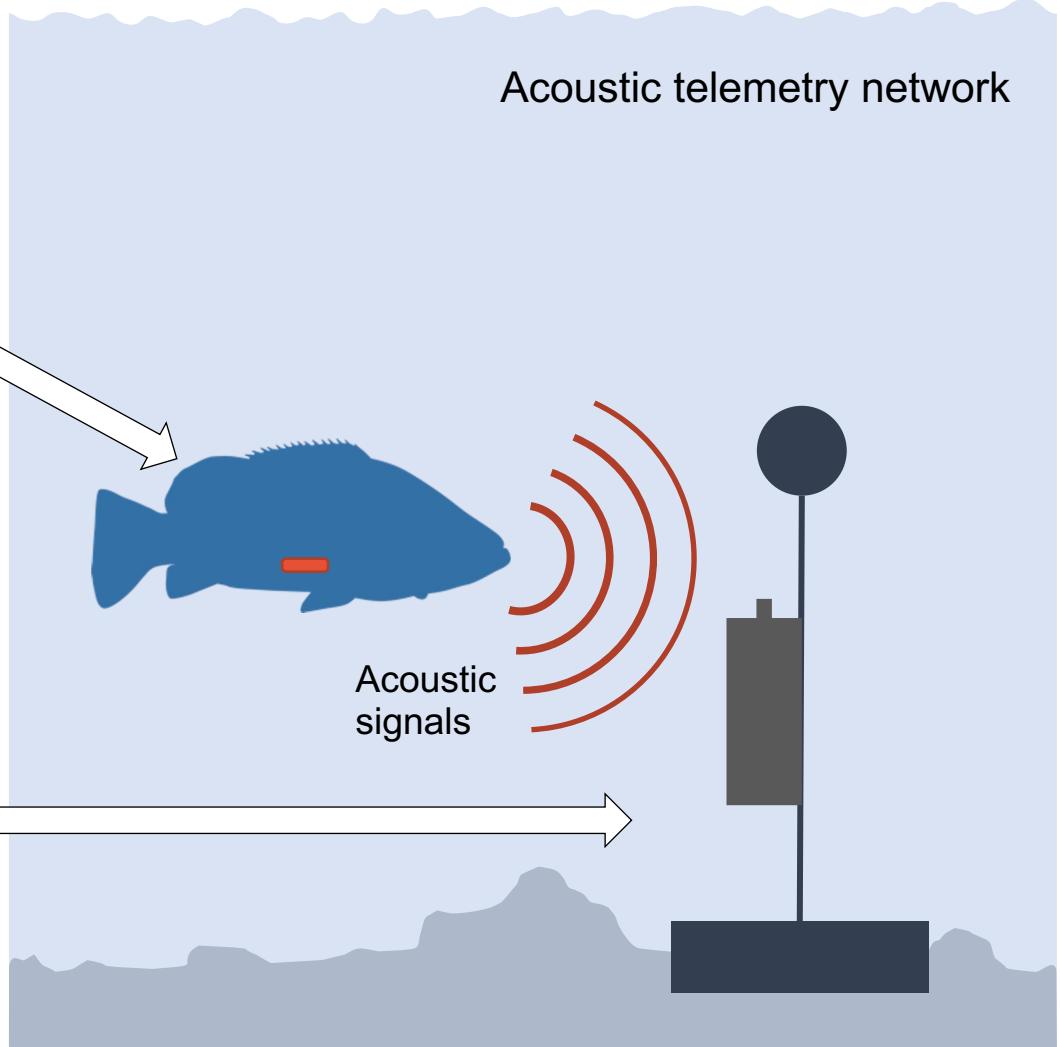
Transmitter



Receiver



Acoustic telemetry network

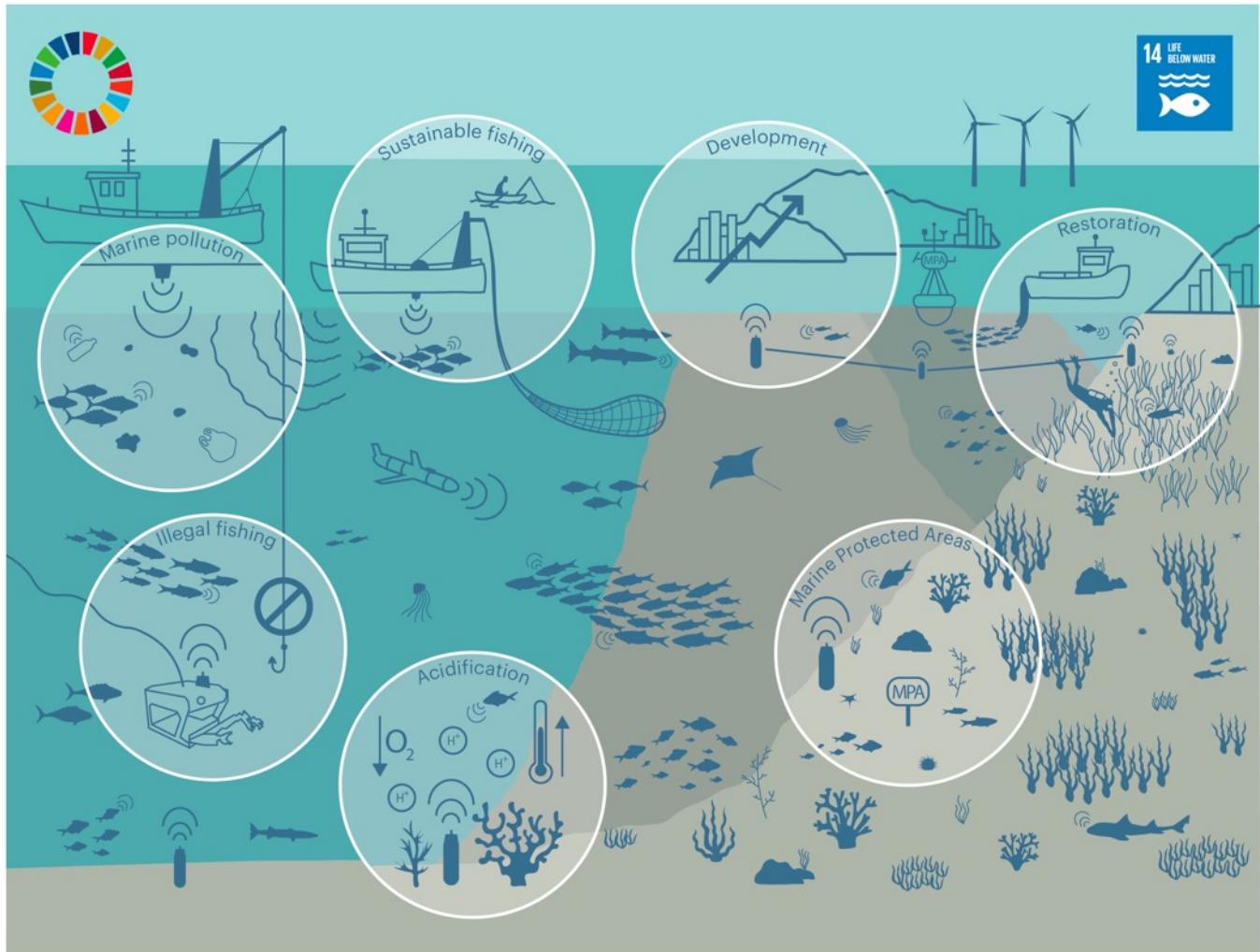


# Acoustic Telemetry

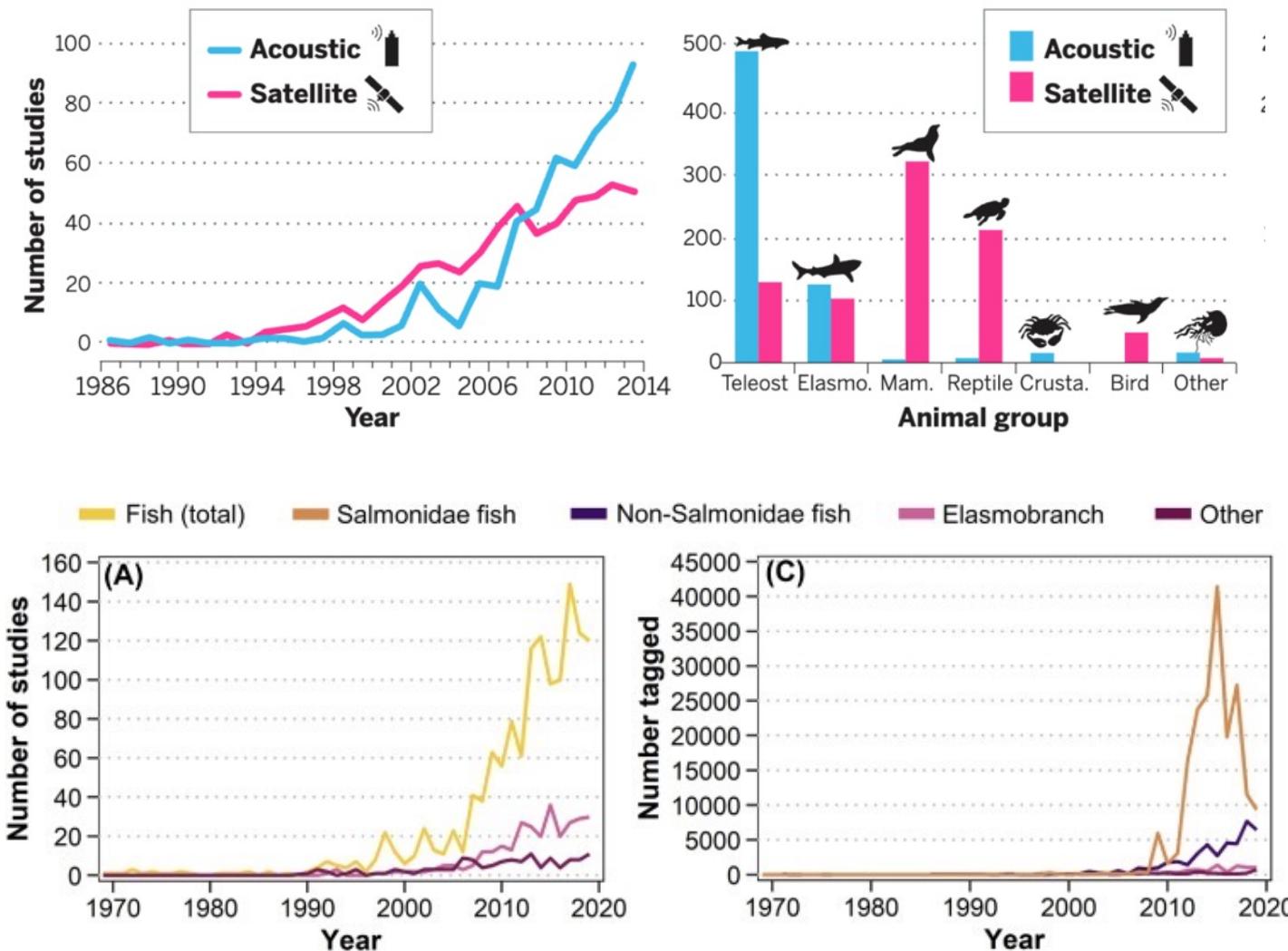
Key tool to study the **movement and behaviour** of aquatic organisms

Applications:

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



# Acoustic Telemetry



## ECOLOGY

## Aquatic animal telemetry: A panoramic window into the underwater world

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

Trends in  
Ecology & Evolution

CellPress  
OPEN ACCESS

## Review

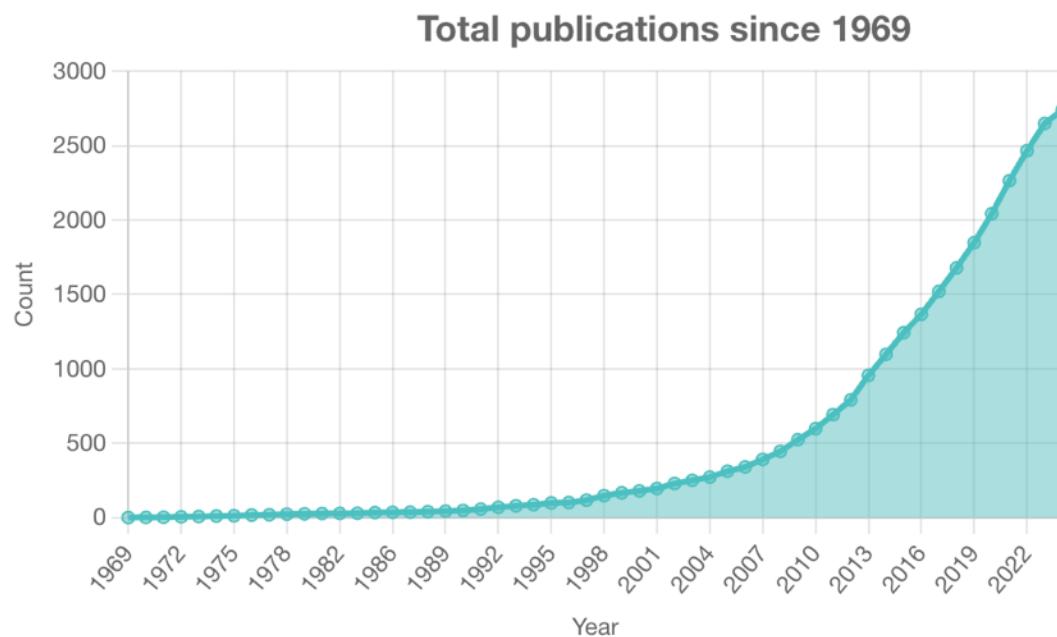
Global trends in aquatic animal tracking with acoustic telemetry

Jordan K. Matley,<sup>1,18,19,\*</sup> Natalie V. Klinard,<sup>2,19,\*</sup> Ana P. Barbosa Martins,<sup>2,20</sup> Kim Aarestrup,<sup>3</sup> Eneko Aspíllaga,<sup>4,20</sup> Steven J. Cooke,<sup>5,20</sup> Paul D. Cowley,<sup>6</sup> Michelle R. Heupel,<sup>7,20</sup> Christopher G. Lowe,<sup>8,20</sup> Susan K. Lowerre-Barbieri,<sup>9,10,20</sup> Hiromichi Mitamura,<sup>11</sup> Jean-Sébastien Moore,<sup>12,20</sup> Colin A. Simpfendorfer,<sup>13,20</sup> Michael J.W. Stokesbury,<sup>14,20</sup> Matthew D. Taylor,<sup>15</sup> Eva B. Thorstad,<sup>16,20</sup> Christopher S. Vandergoot,<sup>17,20</sup> and Aaron T. Fisk<sup>1,20</sup>

Hussey et al., 2015. *Science*, 348: 1255642  
<https://doi.org/10.1126/science.1255642>

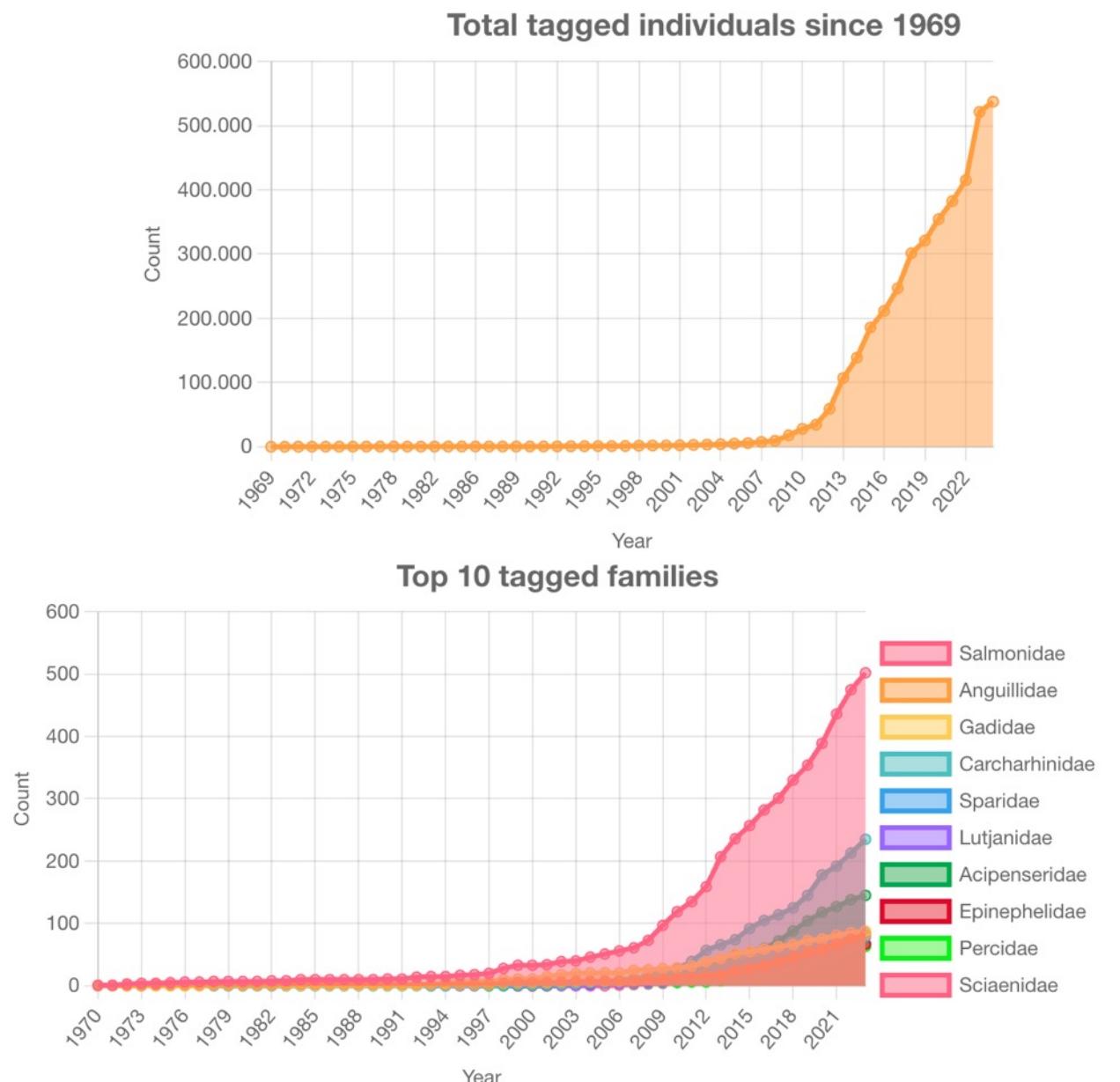
Matley et al., 2022. *Trends Ecol. Evo.*, 37: 79-94  
<https://doi.org/10.1016/j.tree.2021.09.001>

<https://www.trackdat.org/>

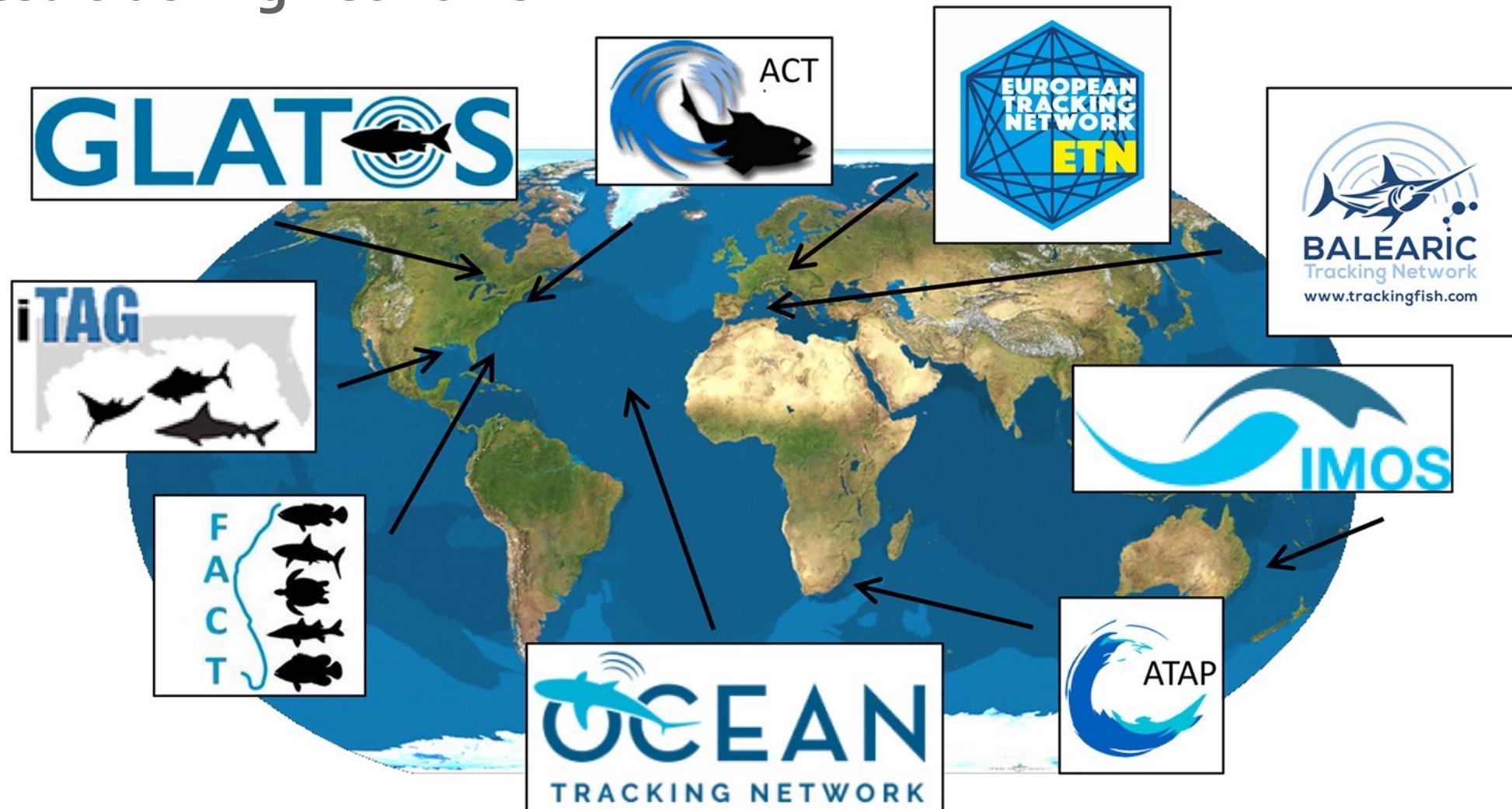


Matley et al., 2024. *Sci. Data*, 11: 143

<https://doi.org/10.1038/s41597-024-02969-y>



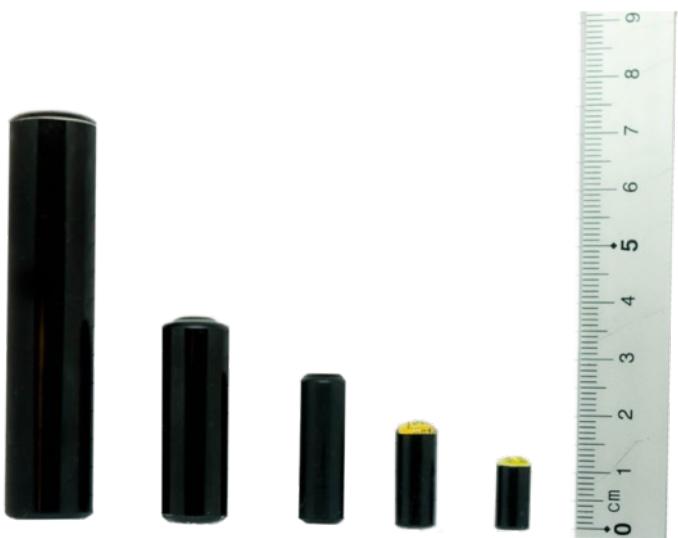
# Integrated tracking networks



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

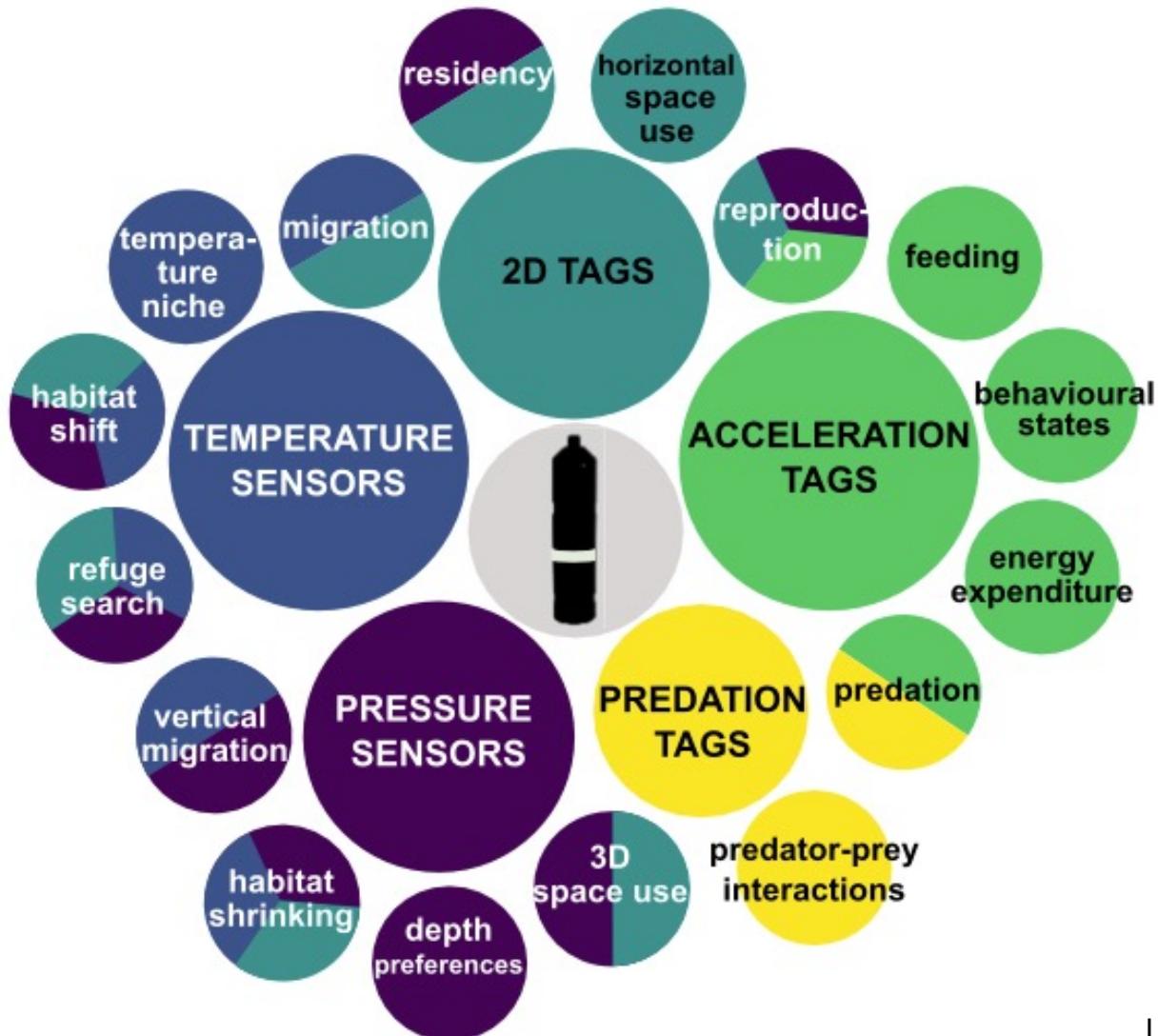
## SENSORS:

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



Source: Thelma Biotel  
[www.thelmabiotel.com](http://www.thelmabiotel.com)

# Sensor tags



# Acoustic transmitters implantation





BALEARIC

62 63 64 65 66 67 68

60 59 58 57 56 55 54 53 52 51

50 49 48 47 46 45 44 43 42 41

# Acoustic transmitters implantation



# Acoustic transmitters implantation



# 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](http://www.thelmabiotel.com)

## RECEIVERS

THELMA BIOTEL



TBR-800

Lotek



WHS-6K

SONOTRONICS



SUR

INNOVA SEA



VR2W /VR2-AR  
MAP-114 – MAP-115

## TRANSMITTERS



ID-HPX / ID-LPX  
OPi – OPs – R64K



MM-R-X  
OPi – OPs



IBT/CT/CHP  
OPi – OPs

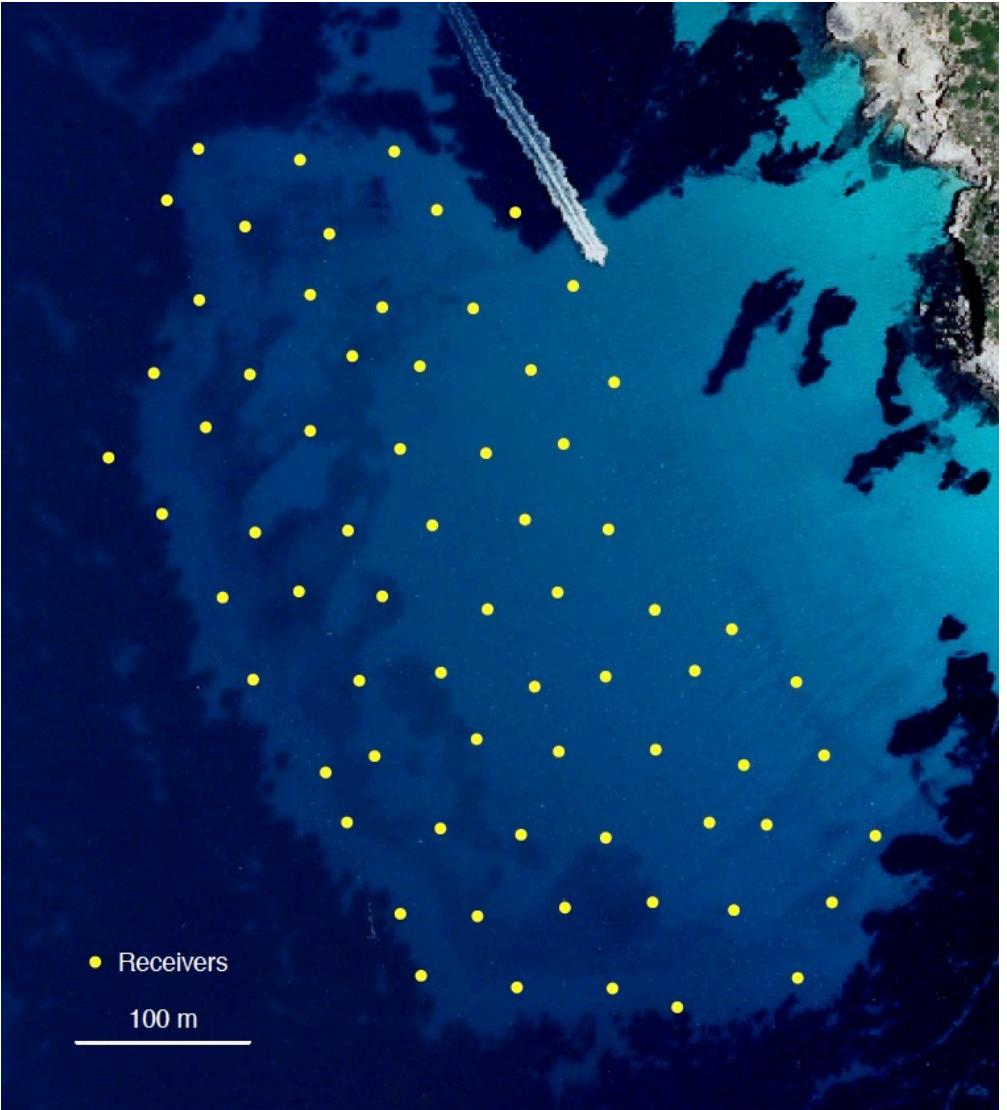


V9-2X  
A69-1602 – A69-9007

# Acoustic receiver installation



# Acoustic receiver arrays

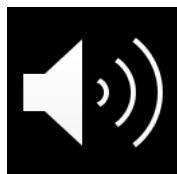


# Signal emission systems

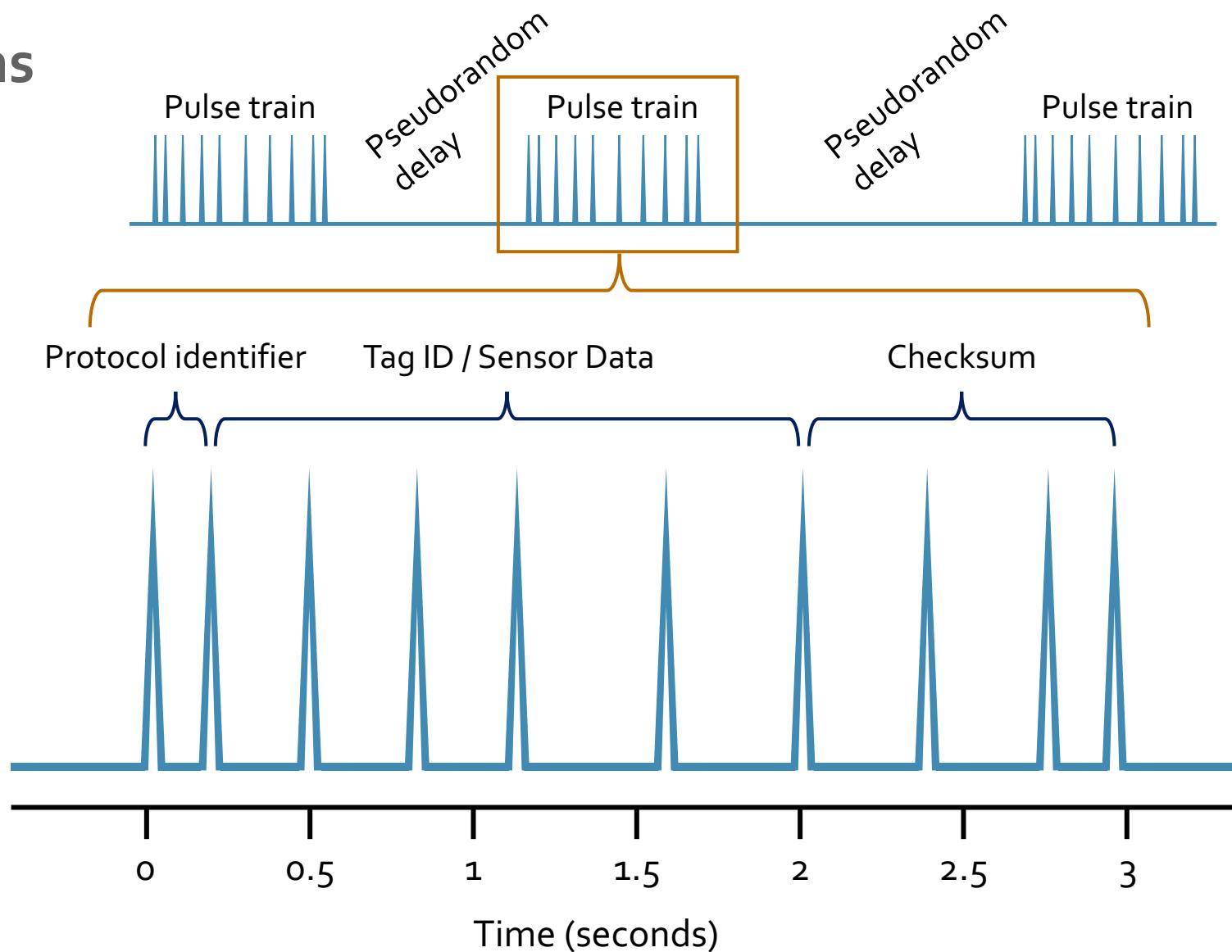
# Signal transmission systems

## 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](http://www.lotek.com)



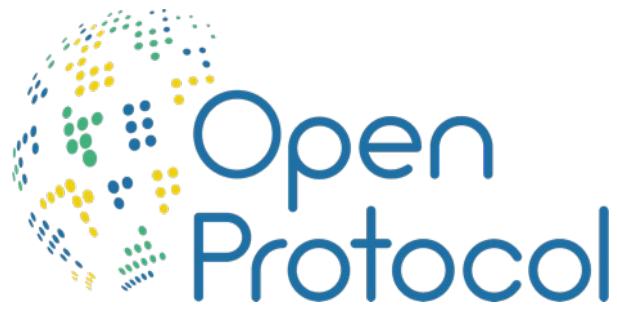
# Acoustic protocols

Protocols

Manufacturers

	Thelma	Sonotronics	Lotek	Innovasea (Vemco)				
				MAP-110	MAP-112	MAP-113	MAP-114	MAP-115
OPi	+	+	+					
OPs	+	+	+					
R64K (A69-1303)	+	+	+	+	+	+	+	
S256 (A69-1105)	+	+	+	+	+	+		
Ro4K (A69-1206)	+	+		+	+			
R256 (A69-1008)	+			+				
H256	+							
DS256	+							
Ro1M	+							
S64K	+							
ACT		+						
MAP			+					
A69-9001, A69-9002, A69-9004					+	+	+	+
A69-9005					+			
A69-1601					+	+	+	+
A69-9006					+	+		
A69-1602					+	+		

# Open Protocols



- 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



 Important information for acoustic telemetry users.

You can find our Memorandum of Understanding [here](#).

Signed Memorandum of Understanding for Open Protocol ID allocation:

- [Lotek](#)
- [Sonotronics](#)
- [Thelma Biotele](#)
- [Star Oddi](#)
- [Chelonia Limited](#) (without commercial intent)
- [Innovasea](#)
- [SARTI-MAR](#) (without commercial intent)

# Transmission protocols



		Protocols			
		ETN protocols		Shared protocols	
		OPi	OPs	S256	R64K
Receivers	Thelma Biotel	Compatible	Compatible	Compatible	Compatible
	Sonotronics	Compatible	Compatible	Compatible	Compatible
	Lotek	Compatible	Compatible	Compatible	Compatible
Innova sea *	MAP-113	Not compatible	Not compatible	Compatible	Compatible
	MAP-114	Not compatible	Not compatible	Not compatible	Compatible
	MAP-115	Not compatible	Not compatible	Not compatible	Not compatible
	Gen2	\$	\$	Not compatible	Compatible
	Nextrak	Not compatible	Not compatible	Not compatible	Compatible
	OP-only	Compatible	Compatible	Not compatible	Not compatible

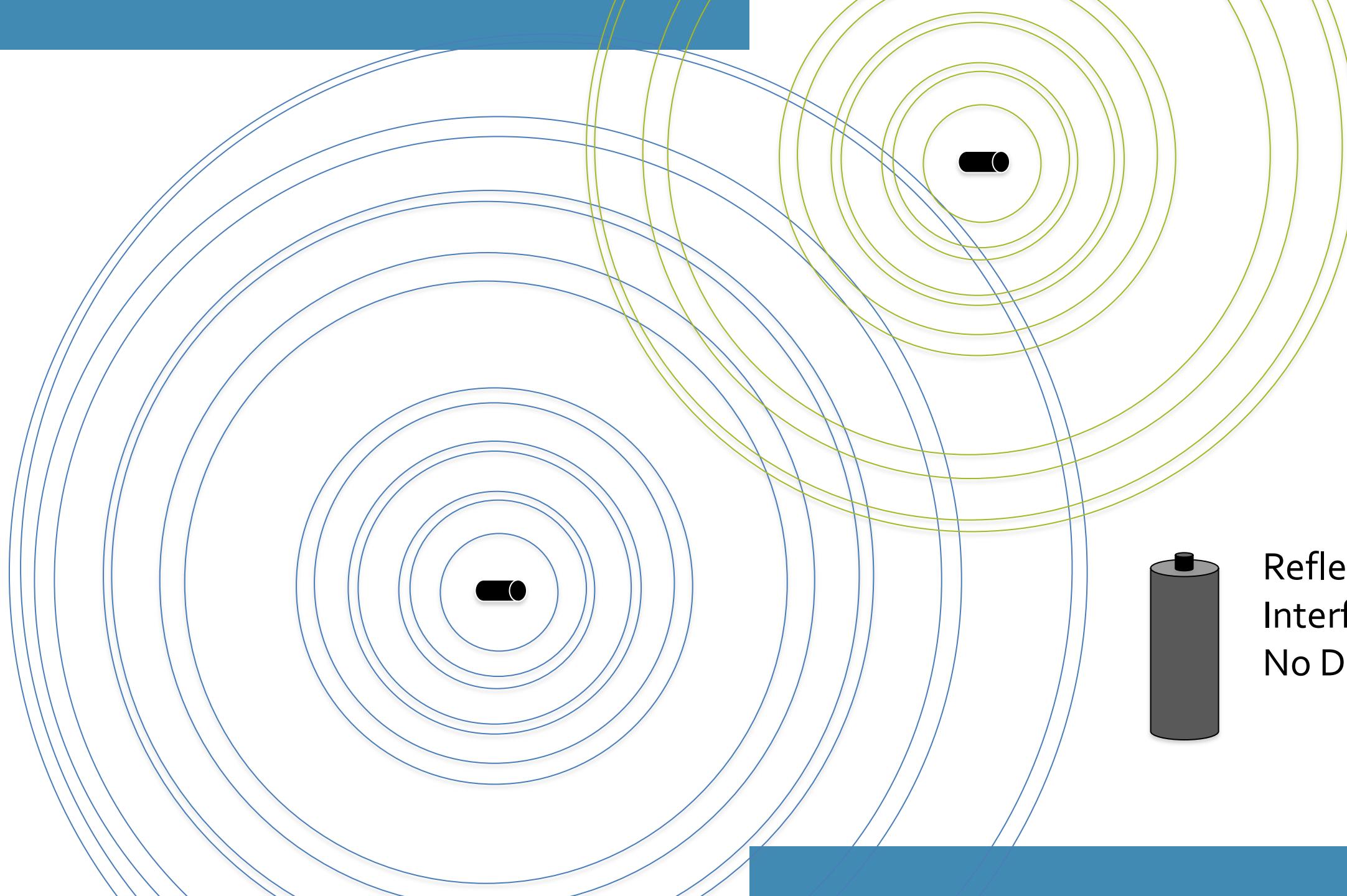
**Legend:**

- Compatible
- Compatible, but Innovasea does not produce R64K tags
- ✗ Not compatible
- \$ Currently only available to ETN members for 300 Euros
- \* Innovasea does not produce OPi & OPs tags
- ETN recommendation

**Annotations:**

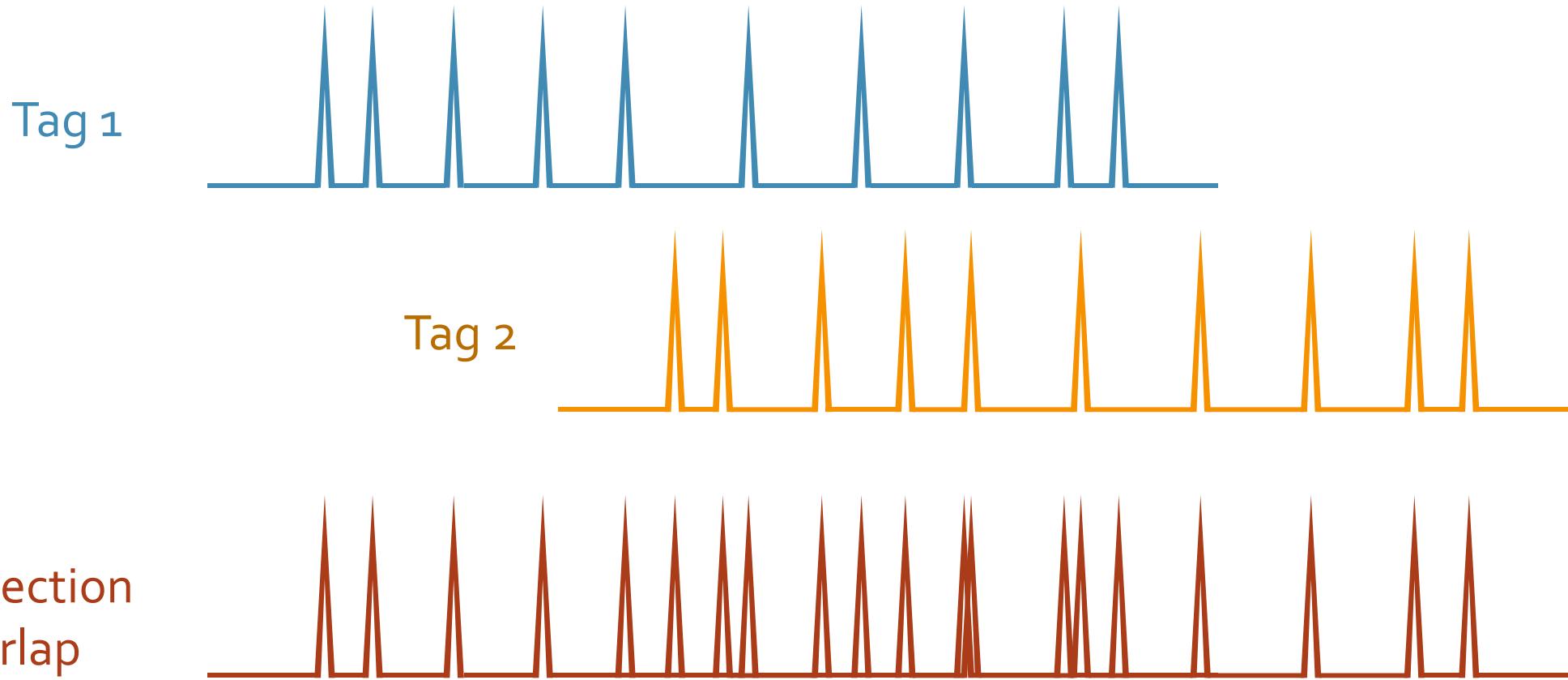
- An arrow points from the "Innovasea has reported that they produce R64K tags again" note to the "Compatible" entry for Innovasea's R64K tag.
- A handwritten note "ONLY if OP-enabled!" is written next to the "Compatible" entry for Innovasea's Gen2 receiver.

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



Reflection =  
Interference =  
No Detection!

# Signal interference



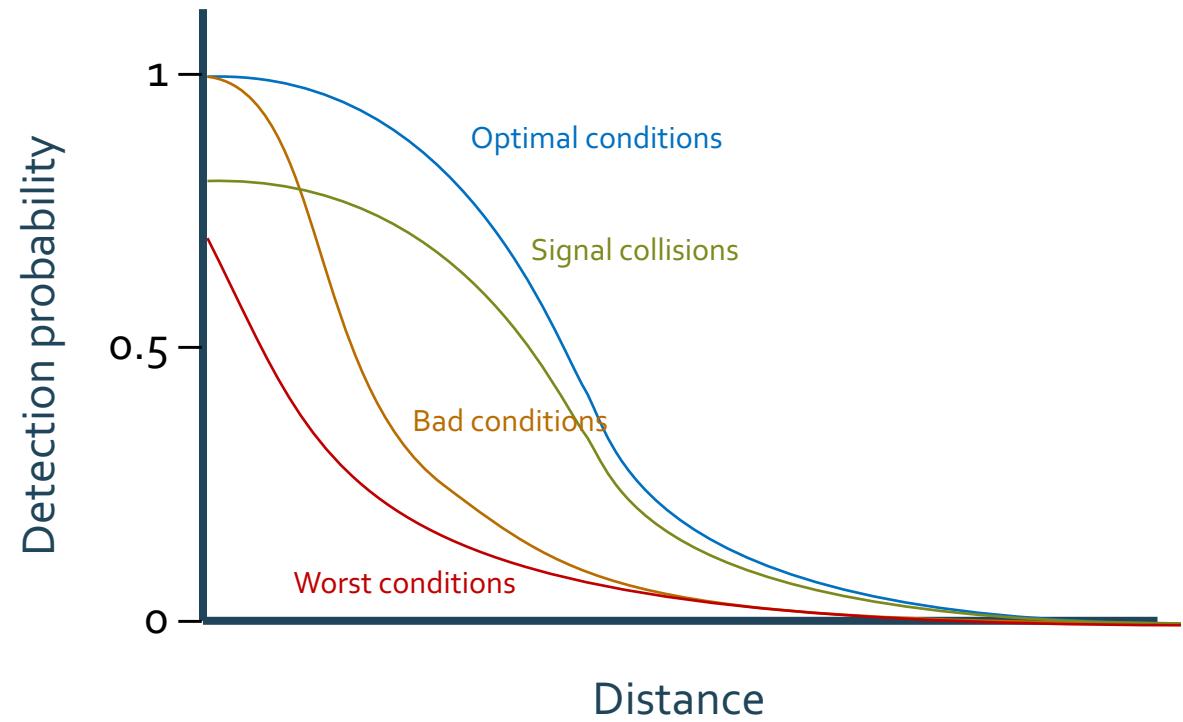
Cancelled signal (no detection)  
False ID (wrong detection)

# Detection probability

## Affected by:

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

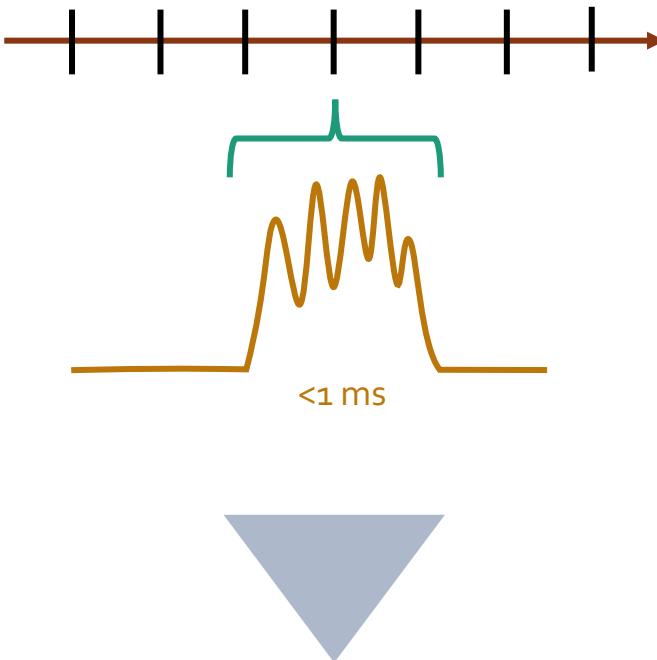
**Importance of range testing!**



# Signal transmission systems

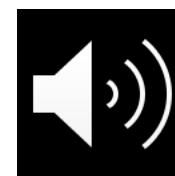
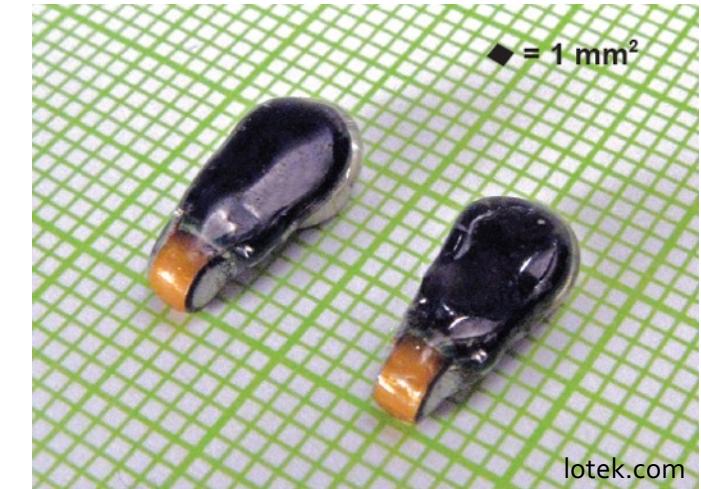
## Binary Phase-Shift Keying (BPSK)

- 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



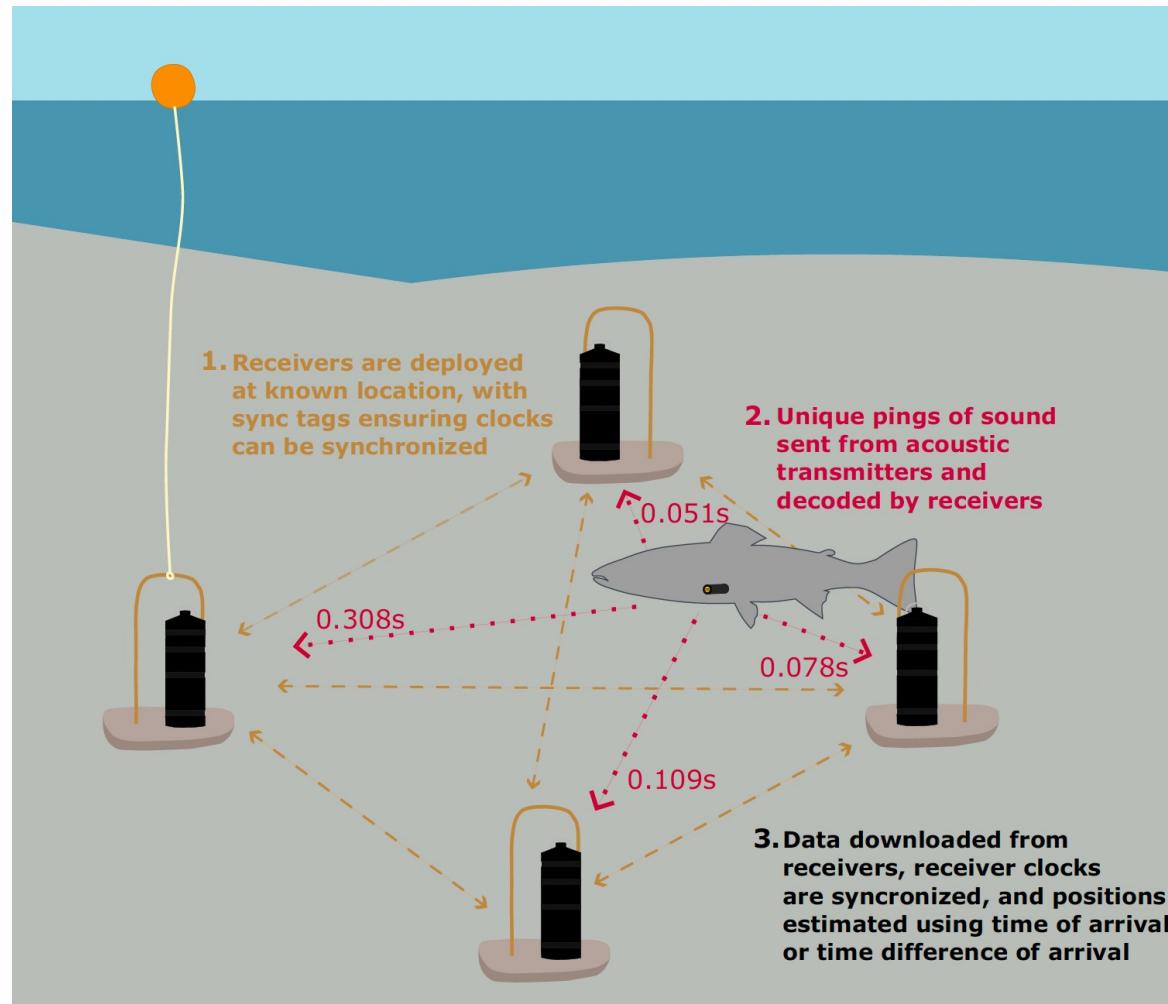
Simultaneous monitoring  
of 1000s of individuals

JSATS system



Source: Lotek Wireless  
[www.lotek.com](http://www.lotek.com)

# Positioning systems



## Positioning aquatic animals with acoustic transmitters

Robert J. Lennox<sup>1,2,3</sup> | Kim Aarestrup<sup>4</sup> | Josep Alós<sup>5</sup> | Robert Arlinghaus<sup>6,7</sup> | Eneko Aspíllaga<sup>5</sup> | Michael G. Bertram<sup>8,9,10</sup> | Kim Birnie-Gauvin<sup>4</sup> | Tomas Brodin<sup>8</sup> | Steven J. Cooke<sup>11</sup> | Lotte S. Dahlma<sup>1,12</sup> | Félicie Dhallenmes<sup>6</sup> | Karl O. Giolland<sup>13</sup> |

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 Biotele	TDOA	No	No

**Time Difference of Arrival (TDOA)**  
 Hyperbolic multilateration  
 Detections in  $\geq 3$  receivers

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

# 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



Project: BTN-IMEDEA\_2023 | ComPort v4.0.3

Connect TBR |

View 1 +

Tag Detection Filter

From: YYYY-MM-DD 15

To: YYYY-MM-DD 15

Receiver:

- 1212 (137484)
- 1213 (13824)
- 1214 (14)

ID Min: 1

ID Max: 1048576

ID (list limited to 500 items)

- 1 (38)
- 2 (23)
- 4 (6)

Protocol:

- OPi-69kHz (172370)
- OPs-69kHz (2)
- R01M-69kHz (6)

Order data view by:

Time Descending

Update View Apply Clear

Tag Detections Table Plot

Receiver status data Table Plot

Export Tag Detections

Filtered (172949)  All (172949)

.csv .tbdb

Date and Time (UTC)	ID	Data	Protocol	SNR	Receiver
2023-02-26 16:59:12.118	54	97	S256-69kHz	18	1638
2023-02-26 16:28:16.602	1281	1	S64K-69kHz	16	1638
2023-02-26 15:34:31.574	3089	-	R64K-69kHz	21	1638
2023-02-26 15:27:16.017	16970	-	R64K-69kHz	18	1638
2023-02-26 15:19:35.003	53002	-	R01M-69kHz	22	1638
2023-02-26 15:14:48.285	38	83	S256-69kHz	18	1638
2023-02-26 15:06:49.313	1	0	S256-69kHz	16	1638
2023-02-26 14:45:11.286	769	-	R64K-69kHz	20	1638
2023-02-26 14:22:55.729	5	0	S256-69kHz	15	1638
2023-02-26 13:44:04.592	50	-	R64K-69kHz	12	1638
2023-02-13 05:26:45.478	12347	-	R64K-69kHz	19	1215
2023-02-13 05:00:42.856	117	185	S256-69kHz	11	1215
2023-02-13 03:58:55.415	2998	-	R64K-69kHz	12	1215
2023-02-13 02:50:34.712	4100	-	R64K-69kHz	12	1215
2023-02-13 01:49:43.704	2098	-	R64K-69kHz	21	1215
2023-02-13 01:43:12.756	10	48	S256-69kHz	17	1215
2023-02-13 01:37:19.553	1793	-	R64K-69kHz	14	1215
2023-02-12 19:37:08.470	4	12	S256-69kHz	16	1213
2023-02-12 19:36:52.547	8	49	S256-69kHz	16	1213
2023-02-12 18:24:01.461	65	139	S256-69kHz	13	1213
2023-02-12 16:57:54.472	35511	-	R64K-69kHz	17	1213
2023-02-12 16:54:19.928	1601	-	R64K-69kHz	13	1213
2023-02-12 16:33:37.383	177	64	S256-69kHz	13	1213
2023-02-12 16:10:50.474	36879	49	S64K-69kHz	13	1213
2023-02-12 15:48:49.020	24661	-	R64K-69kHz	17	1213
2023-02-12 15:13:31.464	166	-	R64K-69kHz	17	1213

Prev. page 1 / 18 Next page (view limited to 10000 items/page)

# Structure of receiver log files



Screenshot of the eCATE software interface showing a list of detections from the database "eCATE\_2018.vdb".

The interface includes a navigation bar with tabs: File, Home, Detections (selected), and Events. Below the tabs are toolbars for Detections, Files, Filters, Stations, and Transmitters.

The main area displays a table of detections with the following columns: Date, Time, Code Space, ID, Transmitter, Receiver, Station, and Data. A total of 3495927 detections are listed.

Date	Time	Code Space	ID	Transmitter	Receiver	Station	Data
2014-08-27	07:00:56	A69-9004	396	EPIMAR-396	VR2W-105297	E19	16.1 m
2014-08-27	07:25:58	A69-9004	396	EPIMAR-396	VR2W-105297	E19	17.3 m
2014-08-27	07:26:17	A69-9004	396	EPIMAR-396	VR2W-125488	E22	17.3 m
2014-08-27	07:28:11	A69-9004	396	EPIMAR-396	VR2W-125488	E22	17.6 m
2014-08-27	07:30:25	A69-9004	396	EPIMAR-396	VR2W-125488	E22	17.9 m
2014-08-27	07:33:17	A69-9004	396	EPIMAR-396	VR2W-125488	E22	17.3 m
2014-08-27	07:36:07	A69-9004	396	EPIMAR-396	VR2W-125488	E22	19.1 m
2014-08-27	07:38:51	A69-9004	396	EPIMAR-396	VR2W-125488	E22	19.4 m
2014-08-27	07:41:21	A69-9004	396	EPIMAR-396	VR2W-125488	E22	18.8 m
2014-08-27	07:43:26	A69-9004	396	EPIMAR-396	VR2W-125488	E22	17.9 m
2014-08-27	07:45:44	A69-9004	396	EPIMAR-396	VR2W-105297	E19	17.6 m
2014-08-27	07:46:02	A69-9004	396	EPIMAR-396	VR2W-125488	E22	17.6 m
2014-08-27	07:48:17	A69-9004	396	EPIMAR-396	VR2W-125488	E22	17.6 m
2014-08-27	07:49:53	A69-9004	396	EPIMAR-396	VR2W-125488	E22	17.3 m
2014-08-27	07:51:30	A69-9004	396	EPIMAR-396	VR2W-125488	E22	17.3 m
2014-08-27	07:53:08	A69-9004	396	EPIMAR-396	VR2W-125488	E22	17.0 m
2014-08-27	07:54:47	A69-9004	396	EPIMAR-396	VR2W-125488	E22	17.6 m
2014-08-27	07:56:29	A69-9004	396	EPIMAR-396	VR2W-125488	E22	17.0 m
2014-08-27	07:58:18	A69-9004	396	EPIMAR-396	VR2W-125488	E22	16.7 m
2014-08-27	08:00:18	A69-9004	396	EPIMAR-396	VR2W-125488	E22	16.4 m
2014-08-27	08:02:44	A69-9004	396	EPIMAR-396	VR2W-125488	E22	16.7 m
2014-08-27	08:04:40	A69-9004	396	EPIMAR-396	VR2W-125488	E22	16.4 m
2014-08-27	08:06:57	A69-9004	396	EPIMAR-396	VR2W-125488	E22	17.0 m
2014-08-27	08:08:34	A69-9004	396	EPIMAR-396	VR2W-125488	E22	17.9 m

# Online data platforms

523  
users4729  
active deployments22991  
tags152  
species904  
million + detections

ETN

## ETN - European tracking network

[Login](#)

Data platform, featuring **521589504** detections

This map shows an overview of all ETN network projects

**ETN**

The ETN data portal is developed by the Flanders Marine Institute as part of the Flemish contribution to LifeWatch.

Contact us [✉](#)

**Documents**

[Data manual](#) | [Quick guide](#)  
[Data policy](#)  
[ETN project template](#)

**Some statistics**

2143 active deployments  
15657 tagged animals, 104 species  
337 users - 103 institutes - 383 projects

**Useful links**

[Lifewatch](#)  
[Data explorer \(R-shiny\)](#)  
[R-studio](#)

This service is powered by LifeWatch Belgium [Learn more](#)

# Examples of applications

# Dusky grouper (*Epinephelus marginatus*)

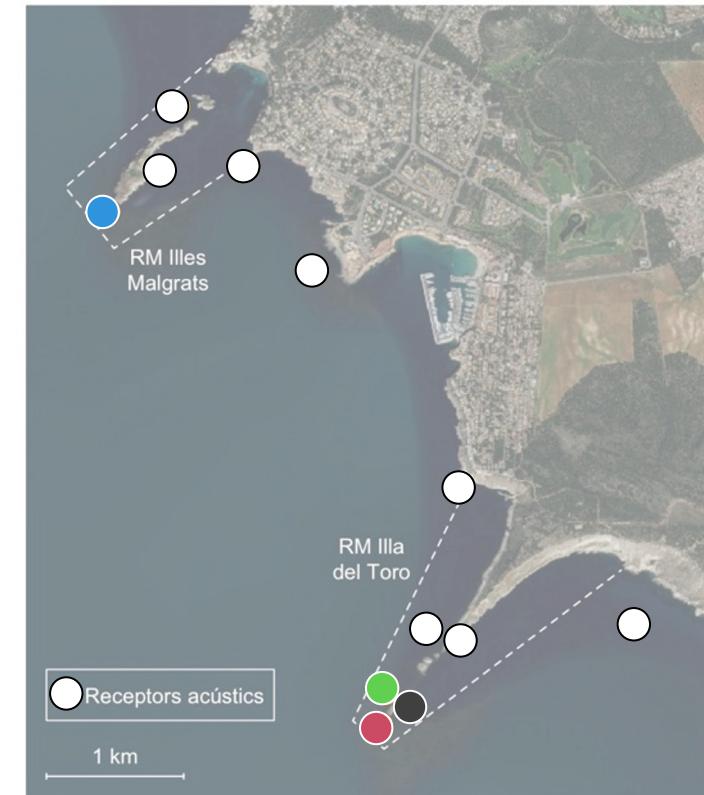
## Long-term residence and movement patterns

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



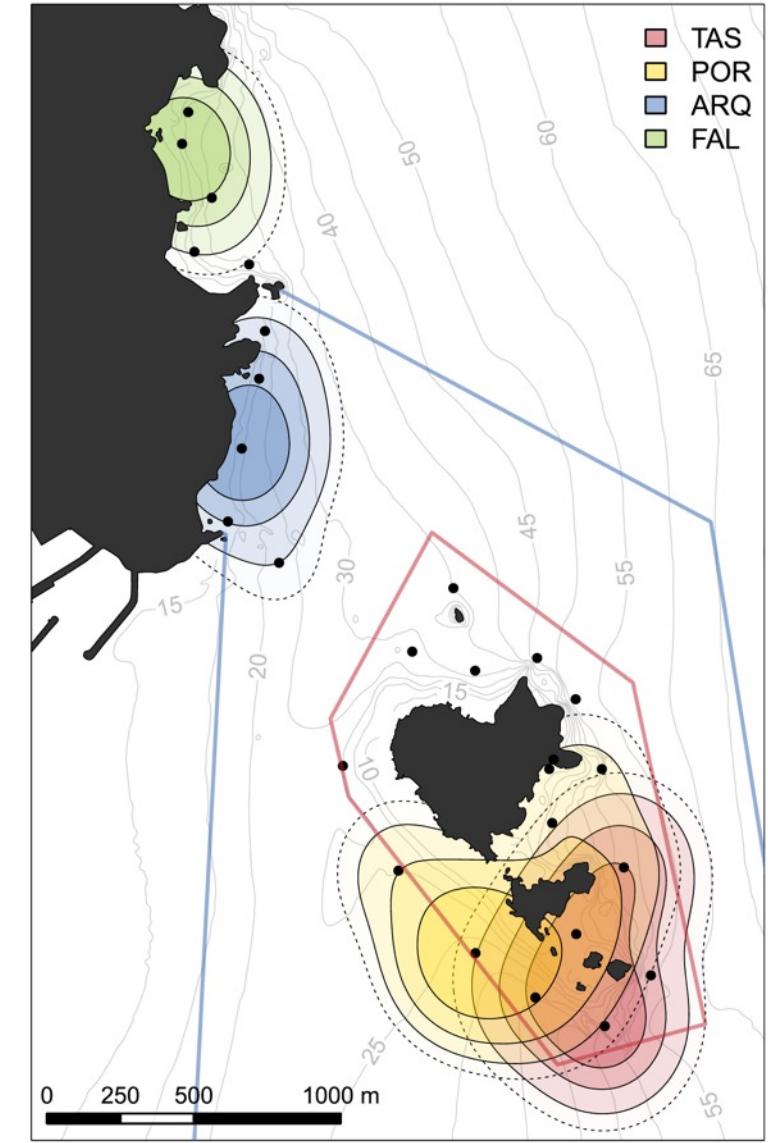
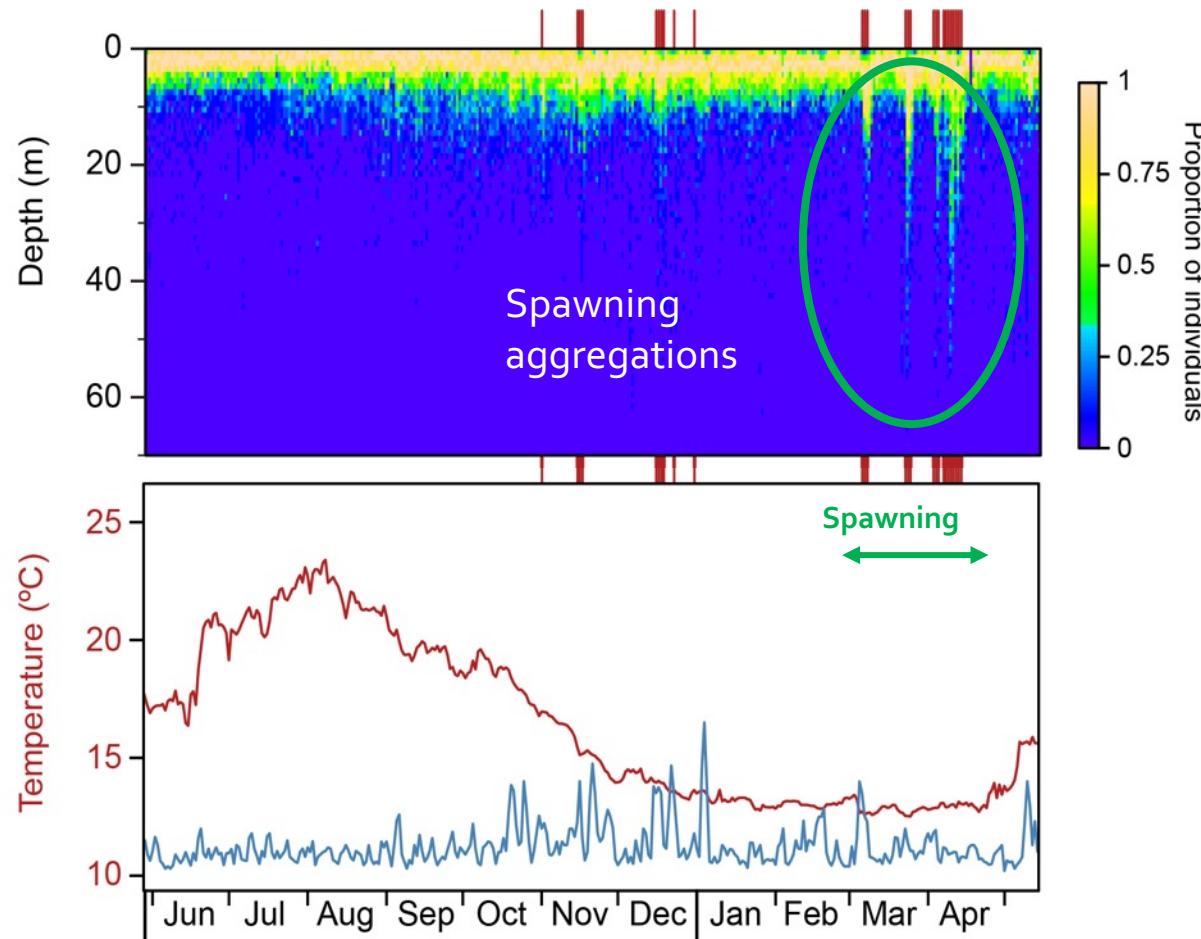
# Dusky grouper (*Epinephelus marginatus*)

## Long-term residence and movement patterns



# Home-range analysis

White seabream (*Diplodus sargus*)



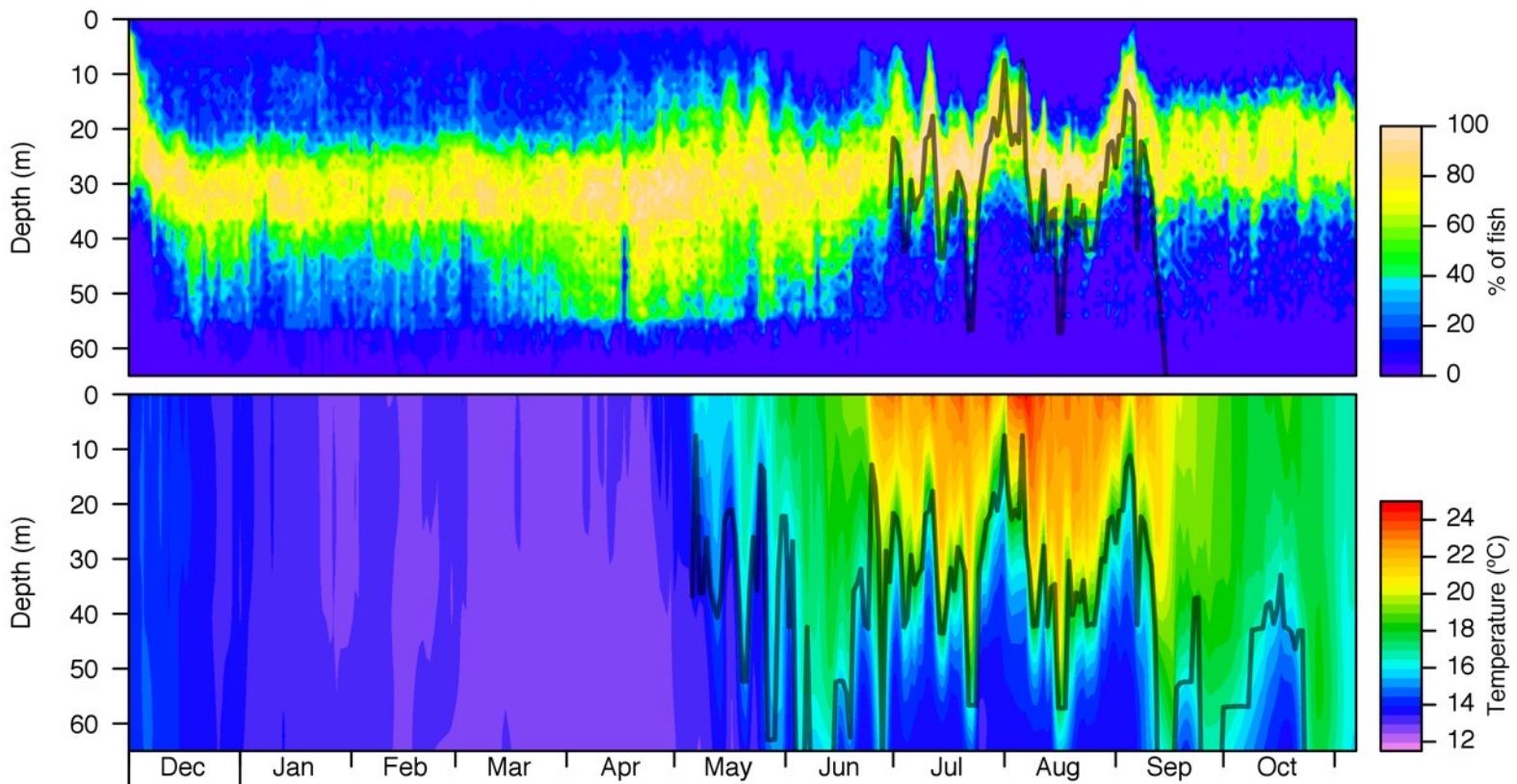
Aspíllaga et al., 2016. PLoS ONE., 11(7): e0159813.  
<https://doi.org/10.1371/journal.pone.0159813>

# Effect of environmental variables

Common dentex (*Dentex dentex*)

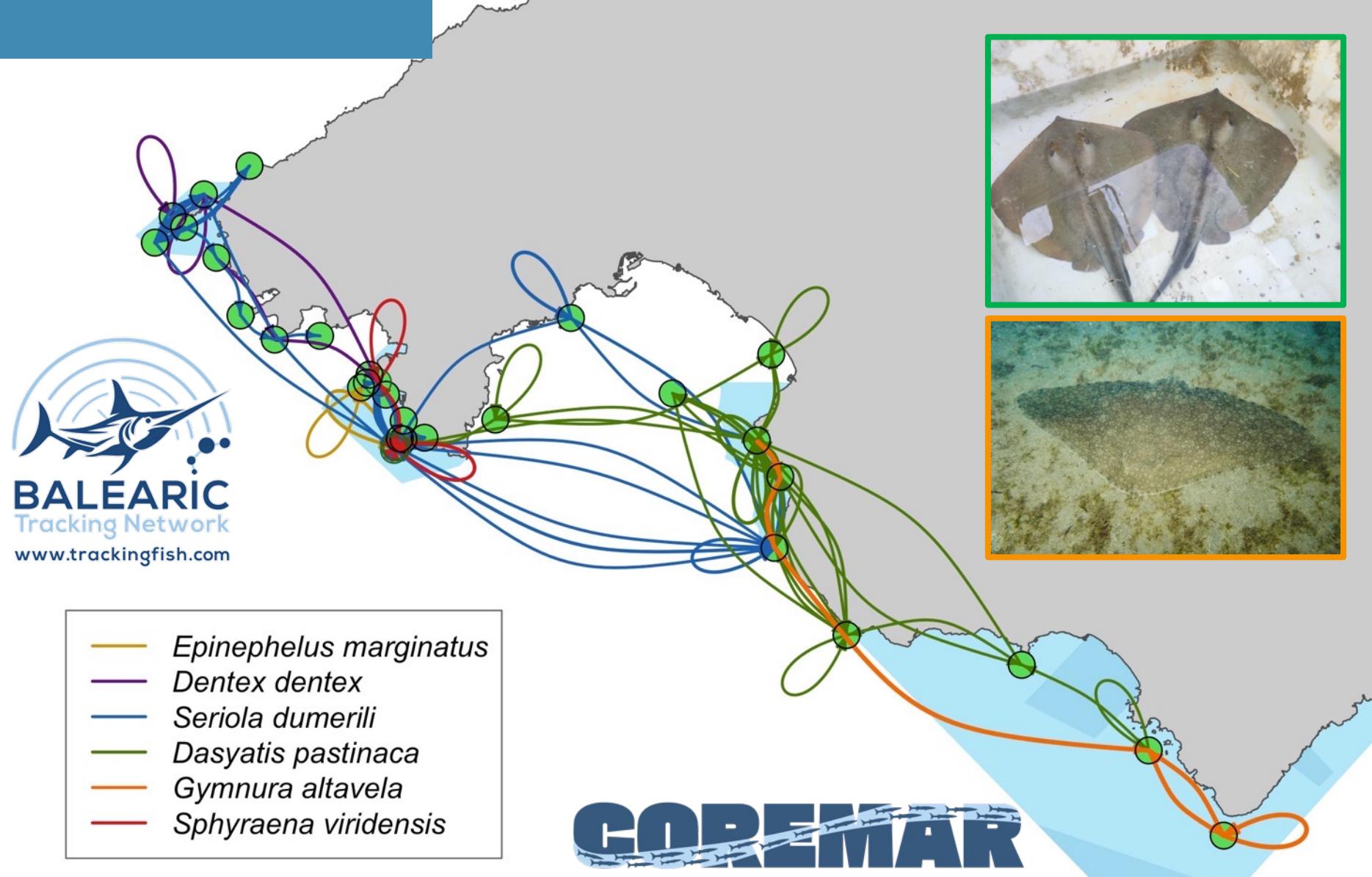


Effect of water stratification  
(thermocline) on vertical  
distribution and activity patterns



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

# MPA connectivity



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

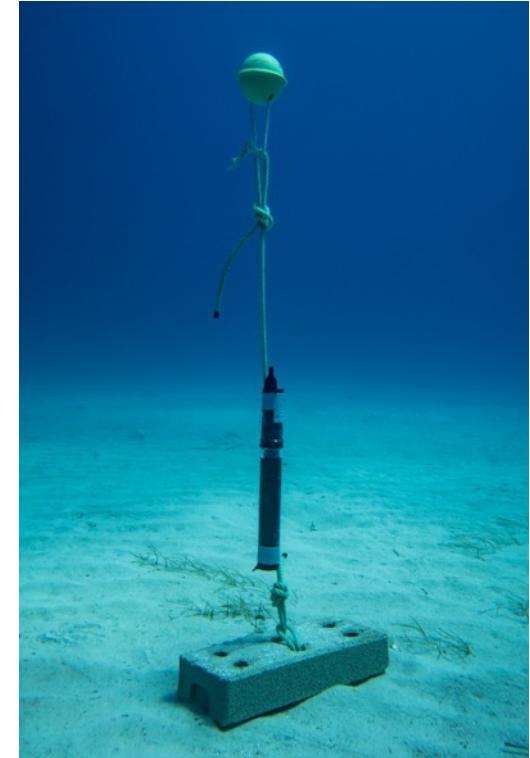


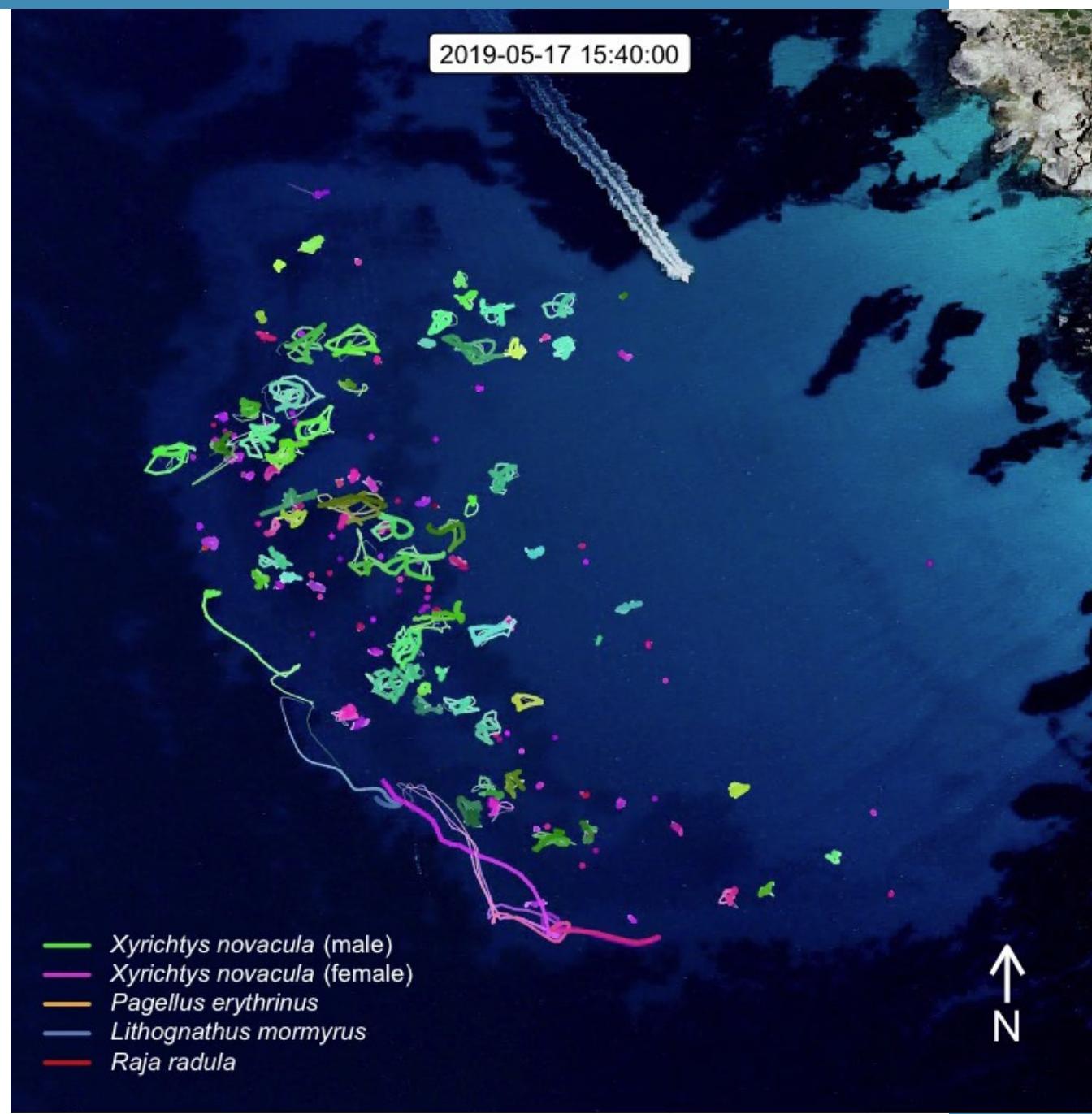
Tagged with **L-AMT series  
transmitters** (Lotek):

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)





METHODOLOGY

Open Access



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

Eneko Aspíllaga<sup>1\*</sup>, Robert Arlinghaus<sup>2,3</sup>, Martina Martorell-Barceló<sup>1</sup>, Guillermo Follana-Berná<sup>1,4</sup>,  
Arancha Lana<sup>1</sup>, Andrea Campos-Candela<sup>1,2</sup> and Josep Alós<sup>1</sup>

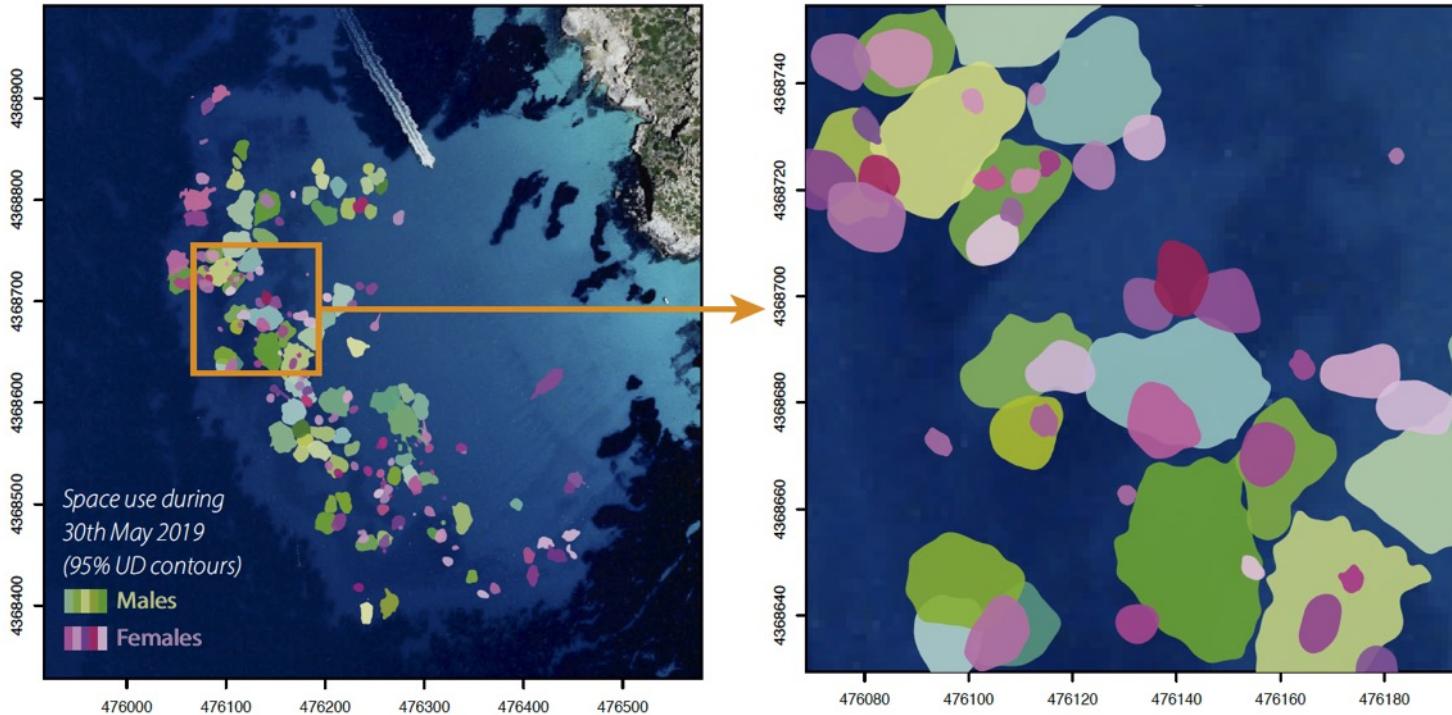
$3.6 \cdot 10^8$  detections  
 $4.2 \cdot 10^7$  raw positions



Photo credit: Martina Martorell

Aspíllaga et al., 2021. *Anim. Biotelem.* 9: 1  
<https://doi.org/10.1186/s40317-020-00224-w>

# Space-use patterns

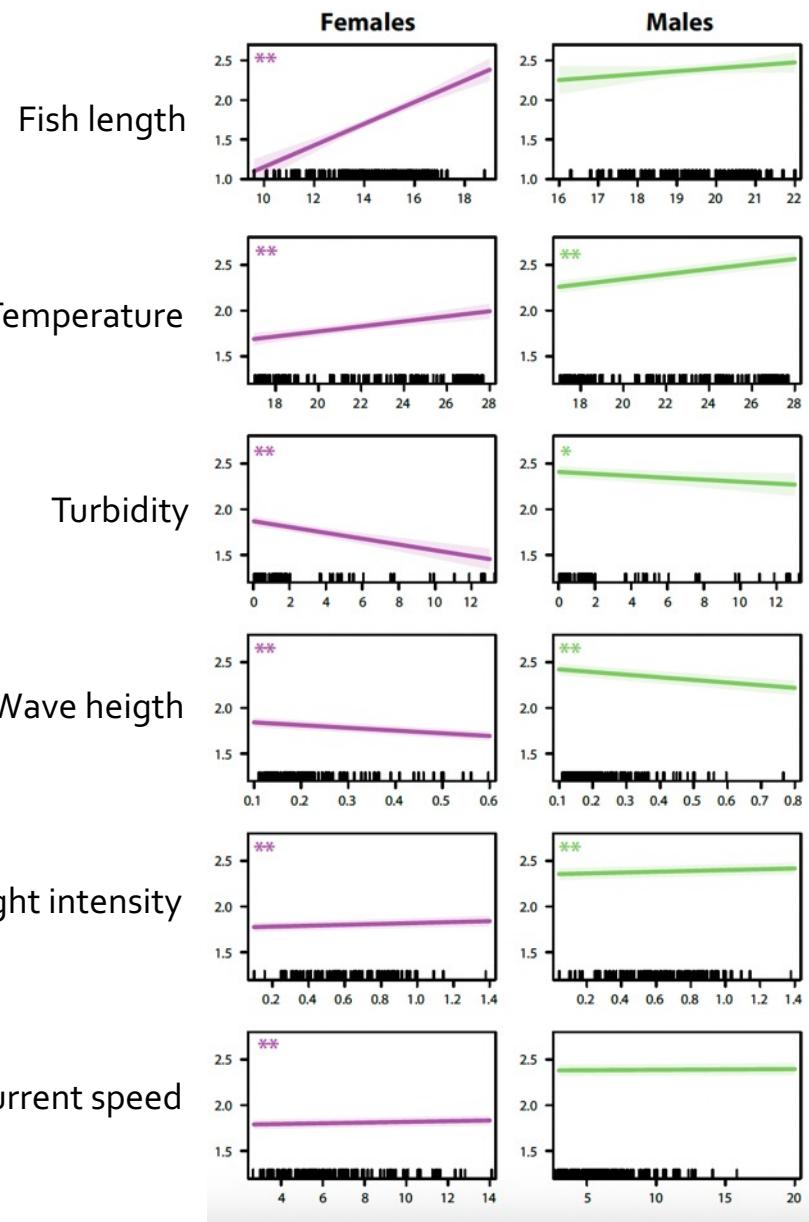


Territorial behavior

Average space use / day:

Females:  $88.5 \pm 82.2 \text{ m}^2$

Males:  $326.1 \pm 211.2 \text{ m}^2$



Jordi Abad's MSc Thesis (2022)

# Social Network Analysis

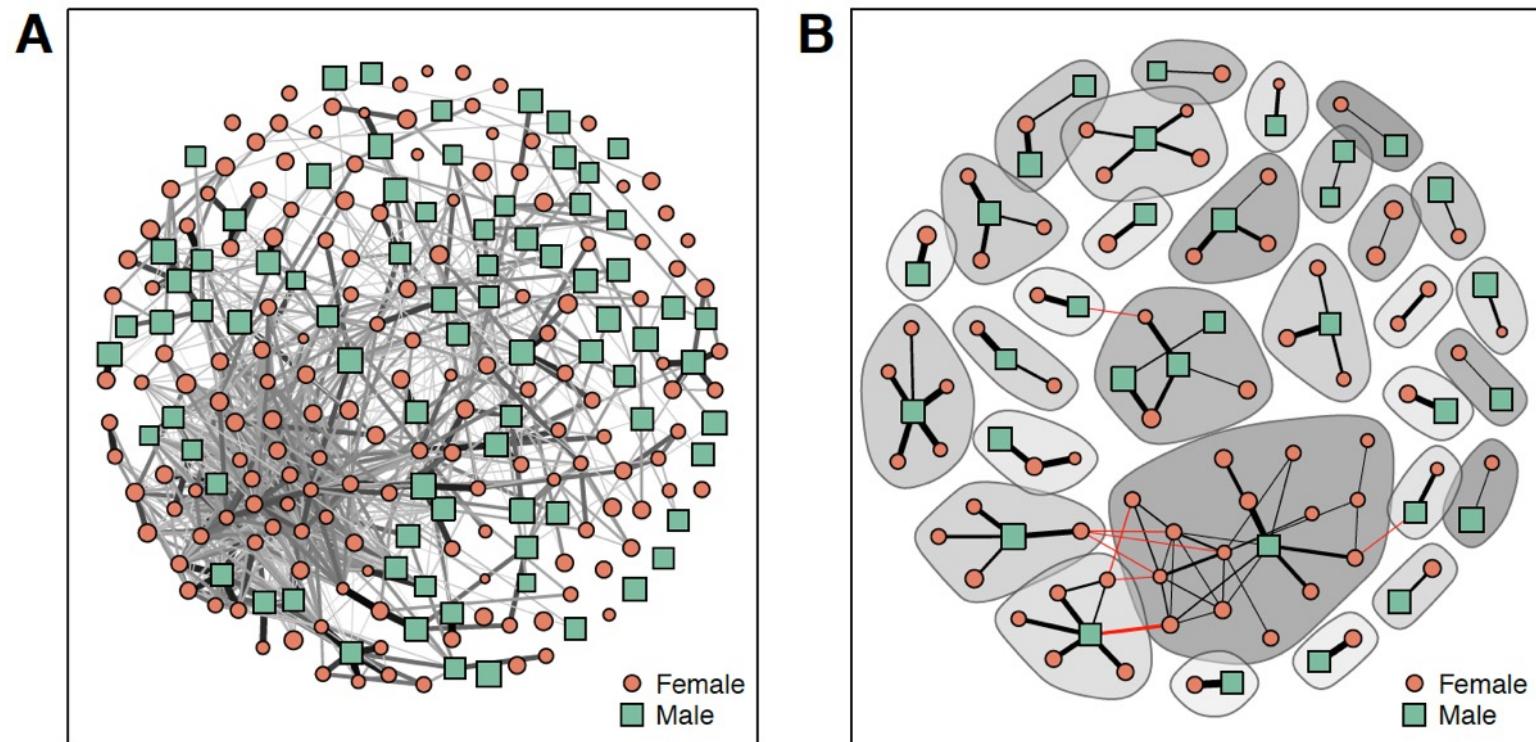
Low interactions between individual of the same sex

Harem structure (1 male, several females)

Punctual aggregations of females

## High-Throughput Tracking of Social Networks in Marine Fish Populations

Eneko Aspíllaga<sup>1\*</sup>, Robert Arlinghaus<sup>2,3</sup>, Martina Martorell-Barceló<sup>1</sup>, Margarida Barceló-Serra<sup>1</sup> and Josep Alós<sup>1</sup>



# Practical session in R

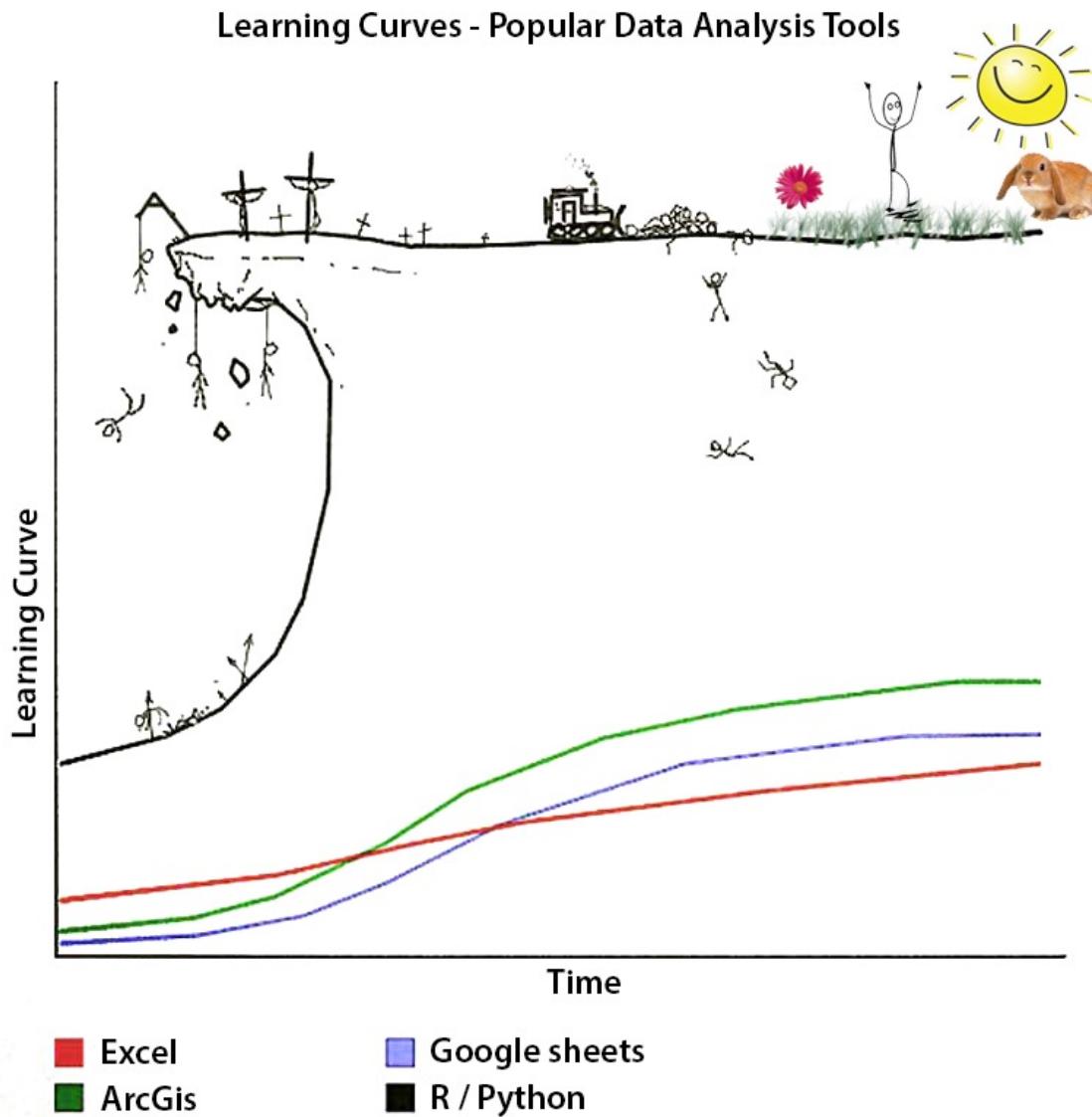
# Why to embrace R



- 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?



## Practical examples

- Example R scripts:

`MASS_01>Loading_and_merging_AT_data.R`

`MASS_02>Analyzing_AT_data.R`