The Marine Station of Dinard, French Museum of Natural History Research to improve knowledge and management of European Eels.

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"Eels and Humans: for better understanding towards an eternal coexistence on earth", 31st Session of the FAO Committee on Fisheries, 9-13 June 2014, Rome

The French Museum of Natural History is a National Research institute that aims to describe, collect and store information on biodiversity and ecosystem functioning world wide. It is also involved in expertise to better conserve & manage biological diversity.

In this Frame, the research team of the Marine Laboratory of Dinard, has been working for more than 20 years to better understand some of the unsolved mysteries of the Anguillid eels both in Europe & North Africa, but also in the Indo-Pacific region.

The feature topics focus on the marine stages: spawning locations and migration routes of leptocephalii, population ecology during growth stages, triggers of downstream migration and marine migration of silver eels, effect of contamination by organic & metallic pollutants on life history & quality of silver eels.

Our research takes place in Europe and Northern Africa, together with the South West Indian and South Pacific Oceans. We combine field research (long term monitoring, sampling in rivers and individual PIT tag surveys, research cruises operated by the University of Tokyo), experimental research (swim tunnels, telemetry), trace element analysis (otolith micro-chemistry), modeling of larval transport & silver eel migration

1 Long term monitoring of eel populations

Three contrasted systems have been monitored since the mid nineties to understand ecological processes involved in the population trends

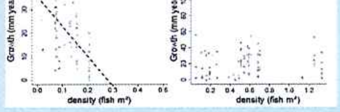
- Since 1990, Escapement of silver eels has dropped by 30% in rivers of Western Europe including , the Loire River (1200 km2: largest river of western Europe) and 20% in small rivers of <100 km2 which cover (Feunteun et al., Acou et al, Trancart et al.). This contrasts with the general decrease of 90% in glass eel recruitment which is reported in Europe and serves as a basis to list European eels among species threatened of extinction.
- Despite a decrease in the silver eel escapement, the carrying capacity of small river systems is still achieved: mortality rates remain high while growth rates are still very low (2 cm yr^{-1}). In contrast, the sex ratio is skewed to females and age at silvering becomes higher
- Density dependent processes, show that mortality and growth rates are influenced by the relative density (percentage of the carrying capacity of river habitats). The higher the density and the higher the mortality and growth rates (PhD of Clarisse Boulenger)

Wolf trap & silver trap on the Frémur river France


A slow net fishery in the Loire river, France

Population trends of silver eel of the Loire River (Feunteun et al. unpublished data)

Year	Fishing effort (nights)	CPUE (nb eel.-ls⁻¹.night⁻¹)	Nb silver eels marked	Nb silver eels recapt.	Nb eels controlled	Recapture rate (%)	Population size (Pooled-Petersen)
2001-02	647	84	1049	291	46427	15.2	310 000 ± 17 000
2002-03	402	60	1201	153	40448	12.7	318 000 ± 23 000
2003-04	409	67	1071	128	37554	11.9	305 000 ± 30 000
2004-05	323	43	553	72	19097	13.0	135 500 ± 15 000
2005-06	231	60	967	100	10060	10.3	160 000 ± 15 000
2012-13	440	39	675	153	27193	22.6	In process...

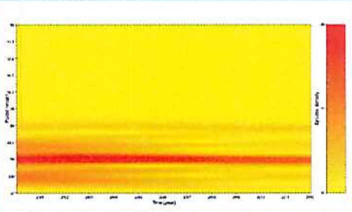


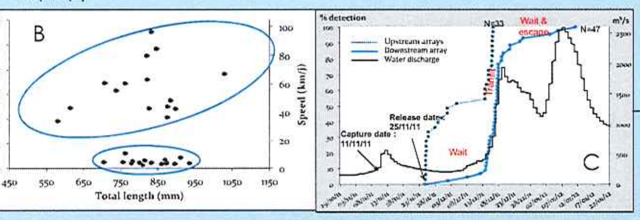
Growth rate (mm year^{-1}) relative to density of European eels (fish m^{-2}) in (a) the Oir River, and b) the Frémur River. The best descriptor of the DDG relationship found on the Oir River is represented by a dotted line. (Boulenger et al. in prep.)

2 Migration of Silver eels

Migration behaviour and dynamics of silver eels, from rivers to the sea and from the coast to the spawning areas are among the most poorly known phases of the eel's biological cycle.

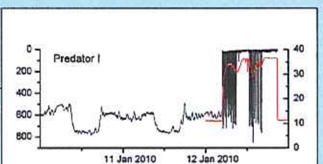
- Deterministic and cyclic models were used to predict the timing of silver eels' dowstream migration. Cyclic models are useful to predict migration peaks with a weekly accuracy, while the resolution of the models enable to predict migration peaks on daily basis when using environmental cues as variations of river discharge, temperature, turbidity, etc.
- Silver eels adjust their downstream migration to temperature and currents velocity in order to facilitate seaward orientation and reduce cost of transport (Bultel et al. 2013). In rivers obstructed by dams, the migration behaviour is disrupted: some eels delay or stop their runs. Overall migration success is impacted (Besson et al. In prep)


Short-term Fourier transform analysis results for silver eel catches in the Oir River from 2000 to 2012. The colour level is a function of the spectral density of periods present in the time series, with red for high density and yellow for low density.
(Trancart et al., 2013, Endangered species research)



Downstream migration behaviour of silver eels in a large River system inferred from acoustic telemetry. (Bultel et al., 2013, Estuarine & coastal science)
A) Acoustic array deployment in the Loire river.
B) Migration speeds & size (two behaviour groups)
C) Migration timing and relation to river discharge

- Silver eels were marked during eeliad project (www.eeliad.org) with 100 satellite pop off tags and ca 300 float tags, including a number from the Loire River. Results are still being analysed, but all routes converge to Azores; migration speed ranges from 25 to 45 km per day, and eels undergo daily diel vertical migrations from 50-100 m deep at night and 500-1200 deep at night.
- An outstanding result was to show predation by marine mammals (pilot whales) and to provide unique information on their feeding behavior (Walberg etal., 2014, deep sea research).
- The reasons for this behavior are studied using swimm tunnels loaned by the University of Leiden. Such behaviour provokes and extra energy cost for transport of ca 5-10% which suggests a hidden advantage, probably linked to gonad maturation (Trancart et al. In prep).

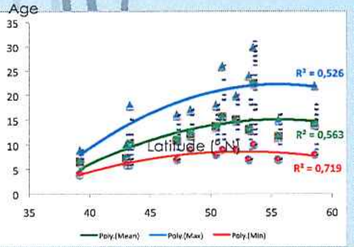


3 Silver eel quality: effect of pollutants & parasites

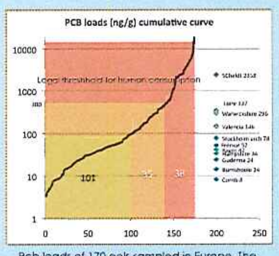
Silver eels age, size, and condition vary according to latitude and habitat conditions as salinity, trophic status and size of catchments. Eeliad project's Work package aimed to understand the effects of pollutants and invasive parasite loads on biological traits of European silver eels.

- All silver eels are contaminated by organic PCBs and other organic compounds (see example below)
- Microcystine (consequence of cyanobacteria blooms due to eutrophication) impede survival (Acou et al. 2008)
- Diversity and abundance of parasite communities affect breeding success (Gérard et al. 2013)

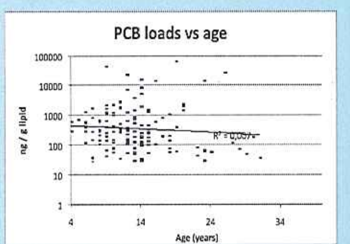
Analyses are still in process, but all contaminants, be they chemical or parasites converge to impact large and old eels (high contamination decreases with age). This is thought to deeply hinder the breeding success of eels and is possibly the first cause of the eels' steep decline.



A highly significant relation between minimum age & latitude. But low relations between max age & average age suggest influence of environmental clues and on silvering age



Pcb loads of 170 eels sampled in Europe. The loads were simply ranked from lowest to highest values. Colours indicate empirical evaluation of impact on silver eel reproduction success.Light green no impact, Orange impact, red heavy impact. On the right, average values of pcb loads per river.



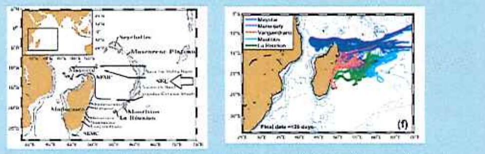
A significant negative relation occurred between age at silvering and pcb concentration. This suggests that old eels are more impacted than young ones and probably reduces the expression of lfe history traits. Therefore, older eels of Northern Europe are exected to be more sensitive to pcb contamination.

4 Spawning areas and ecology of leptocephali assemblages

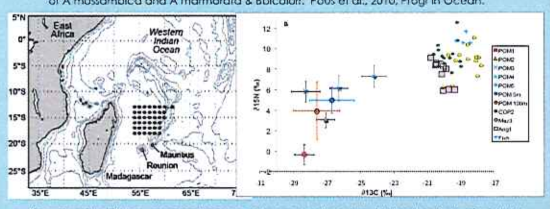

An example of leptocephali assemblage in the south Pacific

- The spawning areas of eels of the south west Indian Ocean were located combining variations of glass eels' age ranges with oceanographic transport models.


Glass eel otoliths, SEM image used for age reading. Robinet et al., 2003


Sampling sites of gass eels of the south west indian ocean (left). And bacward transprt model of the trajectories of leptocephalii .(right). At 120 days (median age at recruitment of the glasse eels) overlapping areas occur. These are thought to be the spawining areas of A mossambica and A marmorata & Bbicolorr. Pous et al., 2010, Progr in Ocean.

- Feeding ecology of leptocephalii were conducted in collaboration with the University of Tokyo. During research cruises, leptocephali, particulate organic matter and mesozooplankton were sampled in the south west Indian Ocean and the South West Pacific where a number of French territories are located. Feeding ecology of leptocephali larvae were inferred from stable isotope markers and fatty acids (unpublished data)



The university of Tokyo organised a cooperative research cruise with the french Muséum in the south west Indian ocean (2010 & 2006). The feeding ecology of leptocephalii was studied. Results suggest that leptocephali feed on POM possibly inluded in marine snow. Feunteun, Miller, Tsukamoto & Otake, unpublished data.

Still much work to do. Most spawning areas and ocean transport of leptocephali are unknown. This has a key importance for international management of eels: most eel species are proposed to be listed on the red list of IUCN.

5

Our research aims to unravel some of the key processes of eel's biology, and has involved many collaborations worldwide including scientists, industrials, fishermen that all share acommon passion for eels. Fundamental discoveries find applications to management of eel populations: IUCN, CITES, EIFAC/ICES working group on eels, French Government for management plans, French Electricity board (EDF), Fishermen, regional councils and water companies... There is still much more work to achieve to ensure a proper management of eels throughout the world.