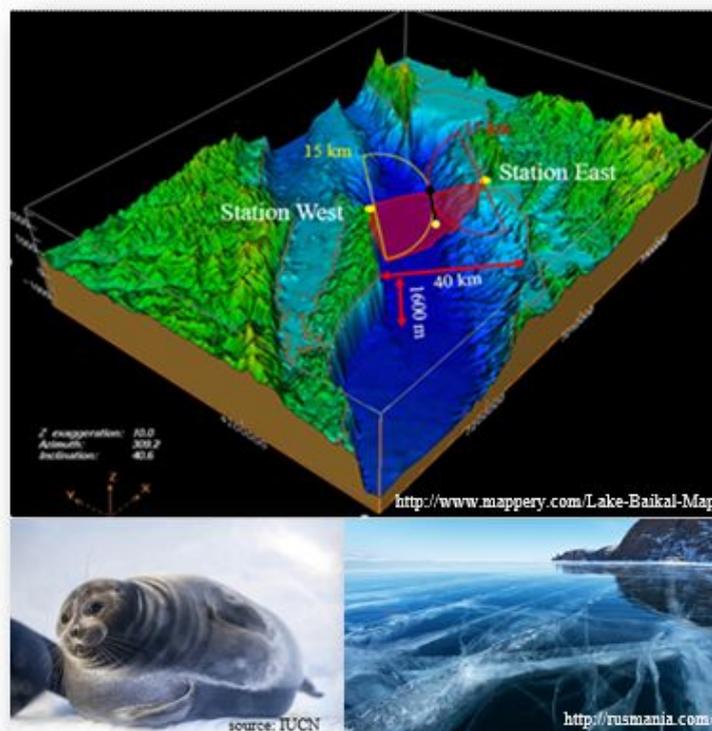


Big data passive acoustic for Baikal lake (Озеро Байкал) Soundscape & Ecosystem Observatory

[B2O]

H. Glotin (Pr), M. Poupard (Phd st.), R. Marxer (Assoc. Pr), M. Ferrari (Phd st.), J. Ricard (IGR),
V. Roger (Phd st.), J. Patris (Assoc. Pr), F. Malige (Dr), P. Giraudet (Assoc. Pr), J.-M. Prevot (IGR),
and M. Komarov (HSE)



EADM group : UMR CNRS LSIS - Univ. Toulon & Aix Marseille Univ., France
National Research University Higher School of Economics, HSE, Moscow

contact : herve.glotin@univ-tln.fr - October 17, 2017

Table of contents

Abstract	5
A. Generality	7
B. Baikal lake and main elements of its trophic chain	7
B.1 The Baikal seal (<i>Pusa sibirica</i>)	9
B.2 The main food of the Baikal seal	12
The endemic <i>Comephorus</i>	12
Endemic <i>Epischura baikalensis</i>	12
C. Setting a permanent Passive Acoustic Observatory	13
D. Methods	15
Objective 1: Characterise the underwater soundscape of Baikal lake	15
D1.1 Installation of robust acoustic & underwater/ice lux-meter stations	15
D1.2 Recordings long time series of lake soundscapes	16
Objective 2: Determine the acoustic repertory of seal	17
D2.1 Determine underwater emissions of seal : big data classification	17
D2.2 Ethoacoustics: variations of seal emission according to external data	17
D2.3 Classify seal vocalizations in airborne environment	18
Objective 3: Determine seal positions / trajectories by big data	19
D3.1 Recordings and 3D monitor presence of Seal	19
D3.2 Matching field model	21
D3.3 Monitoring acoustic propagation in Baikal and sound exposure	21
E. Logistics, Equipment, Schedule, Ressources	22
Schedule / Big data effort = TOTAL per year = 9.2 To / year	23
Ressources	23
F. References	23



Toulon, DYNI CNRS LSIS team, France, 17th of October 2017

Big data passive acoustic Baikal Observatory

[B2O]

To whom it may concern,

we are honoured to present our pilot project B2O that we presented at the big data workshop in Moscow the 12th of october 2017, and then resumed to the scientific advisor of the French embassy the day after.

B2O is proposed to be the first long term bioacoustic observatory of the Baikal Lake, the world's oldest and deepest freshwater lake. It represents the largest freshwater surface in all of Asia. The lake's seals are the superpredators of the ecosystem. The Baikal seal is a truly isolated endemic species, the only pinniped to live solely in freshwater. This project will bring knowledge on seal presence, seasonality, habitat and climate change adaptation, and foraging behaviour and success. The project will deliver a continuous passive acoustic monitoring system, seal tracking data, knowledge about seal swimming behaviour.

The DYNI (Information Dynamics) team is a part of CNRS LSIS laboratory (Laboratoire des sciences de l'information et des systèmes). It regroups the Aix-Marseille Université, the Université de Toulon, the Aix-en-Provence ENSAM and the CNRS. LSIS is composed of 200 researchers professors and PhD students. The main activities of the laboratory cover the fields of computer science, machine learning and signal processing. It is a multidisciplinary team with proven expertise in image/audio processing, big data and deep learning. DYNI leads the Scaled Acoustic Biodiversity program (<http://sabiiod.org>) since 2012, involving interdisciplinary projects on big data for acoustic biodiversity monitoring.

DYNI team has a wide range of experience in monitoring endemic species, such as the Cachalot in Toulon (Glotin 2012, 2015, 2017), the blue whale in South of Chili (Patris et al 2016), Narwal in the Arctic (Glotin et al 2015), and river dolphins of the Amazon (Pacaya reserve Amazonia, Glotin et al 2016-2017 STICAMSud BRILAM project).

B2O is a long term project. We envisage two main lines of collaboration. The first possible collaboration concerns the Higher School of Economics (HSE) (<https://www.hse.ru/en/>). During the first Big Data workshop that took place in Moscow in dec. 2016, and the second on October 12th 2017, we presented B2O at HSE. The main organizers, Prof Komarov (mkomarov@hse.ru) and V. Kornilov, expressed interest towards B2O, and we discussed about a possible master thesis program in

relation with B2O. We then presented B2O to the master class during a lesson of 2 hours in October 2017. Two master students, Dmitry Prokhorenkov <home2d@gmail.com> and Krishna Rukmangada <krshna12.r@gmail.com> have expressed and exchanged the days after great interest and informations in how to get involved in B2O during their master. We would wish then to host HSE Master course trainees in the context of B2O in order to conduct experimentations, observations in the field, and then to train the Big Data acoustic models on our High Performance Computers (GPU farm and deep learning).

A second collaboration could be with Irkutsk State University (<http://isu.ru/fr/>). Pr Glotin met and discussed last year with one representative of ISU during its invitation to the 1st Big Data workshop in Moscow. ISU is strongly engaged on Baikal studies with the Faculty of Biology and Soil Studies, with a significant amount of work on plankton dynamics, amphipods and the structure of the fish population, co-chaired by the UNESCO for Water Resources program that favors the creation of an integrated research system in alliance with foreign universities and develop foreign relations by creating international departments and new educational institutions¹ that we B2O could maybe join. The Department of Invertebrate Zoology and Hydrobiology at ISU works in long-term dynamics of Baikal and developed a composite index (E. Zilov (3952)241927 eugenecilow@gmail.com), reflecting the health status of aquatic ecosystems, which efficacy has been proven in the Baikal lake. This index could be correlated with B2O soundscape index.

Another study on the mechanisms of resistance among endemic Baikal aquatic organisms to stressful environmental factors could also be linked to B2O (M. Timofeev (3952)241927 m.a.timofeyev@gmail.com). Furthermore, the assessment of anthropogenic impact on productivity of fishing ponds in the Irkutsk region could also be a linked to B2O (A. Matveev, V. Samusenok (3952)241855 - matvbaikal@mail.ru).

We are confident on our expertise and possible collaborations after the meetings we had in the two Big Data workshop session in Moscow, and we will be pleased to detail B2O to any interested partner. We will be honoured to initiate first experiments of B2O in beginning of 2018 as DYNi can supply minimal materials to start with, but in any case, such a long term project would require established collaborations and grants.

Thank you for your consideration.

Sincerely,

herve.glotin@univ-tln.fr

Pr H. Glotin, Pi
<http://glotin.univ-tln.fr>



Ass. Pr R. Marxer, co-Pi

marxer@univ-tln.fr
<http://www.ricardmarxer.com>



¹ <http://isu.ru/en/research/activities/UNESCO-Chair.html>

Big data passive acoustic Baikal Observatory

[B2O]

Abstract

Lake Baikal, the world's deepest freshwater lake, 1/5 of the world's fresh water, is the "Russia's Galápagos": much of the fauna here is found nowhere else on Earth. The Baikal lake ecosystem is mainly based on three endemic species: a baikal seal (*Pusa sibirica*), a fish (*Comephorus baikalensis* and *Comephorus dybowskii*) and a copepod (*Epischura baikalensis*). These species are isolated and vulnerable or endangered, mostly due to noise, chemical pollution, global warming. The Baikal seal is one of the main superpredators of the lake and plays a crucial role in the balance of the ecosystem. Like any mammal, seal need to browse and adapt to its environment, and exhibit a large diversity of movement and diving times. Environmental factors, such as anthropogenic sounds and prey availability, play a significant role in such behaviour. One of their main threats is water pollution, and anthropogenic noise is a threat gaining importance as the human activity increases in the area.

B2O is proposed to be the first long term bioacoustic observatory of the Baikal Lake. The project will bring knowledge on seal presence, seasonality, habitat use, and foraging behaviour and success. The project will deliver a continuous passive acoustic monitoring system, seal tracking data, knowledge about seal swimming behaviour in response to changes of their ecosystem.

B2O focuses on passive acoustics big data monitoring to study multiple aspects of the Baikal lake system, such as animals vocal/biosonar behaviour, velocity and trajectory, abundance data, and vessel attendance and movements. Three or two dimensional tracking of the fauna could be produced from multiple channel hydrophone recordings. These tracks will provide insight about seal movements and behaviour according to the context. The revealed tracks, headings and speed, will aid to understand the population and predation of the seal. Furthermore, our passive acoustic tracking system captures social behaviour cues, providing information about groups presence that can be valuable in planning protection of the superpredator of the Baikal lake, thus its ecological balance.

The analysis of seals vocal cues may also contribute to the knowledge of population structure and trend, by the use of size/age/sex frequency or temporal structures correlates of individual vocalisations. In addition, the study of their interaction with surface ships may reveal how the animals react to surface traffic and modify behaviours that are primarily addressed to maintaining their energy intake.

Anthropophony may dramatically reduce the acoustic communication and sensing space of animals, reducing their ability to acoustically detect incoming ships. Recent studies show that 50% of the aquatic noise is generated by 15% of ships and that in some coastal and other high-traffic areas, ship noise has reached levels that degrade habitat for endangered species. An objective of B2O is to assess these noise levels and correlate them with the behaviour of the animals. These results could directly feed into the development of new approaches to the management of the lake's environment.

Moreover, the passive acoustic monitoring of the seal population could indirectly assess the impact of global warming on the behaviour and adaptation of the species. Water and environment characteristics could be jointly analysed with the obtained results to identify any effects of context change.

Overall B2O will provide a new view of the Baikal lake, by characterizing and revealing its underwater and airborne soundscape. B2O will produce new knowledge on the lake's habitat and data that will be of great use to scientific and economic actors of the region and around the world.

The main objectives of the B2O project are :

1. **Characterise the underwater soundscape of the Baikal lake: Acoustic detection of different species composing the food chain and background noise (ice, boat) (2 years)**
 - 1.1. Installation of robust acoustic observatory and luxmeter (first weeks)
 - 1.2. Recording long time series of Baikal soundscapes (seasonal variability)
 - 1.3. Describe the different sounds and their correlation with luminance
 - 1.4. Identify the sound sources : big data (8 Terabytes / year) indexing
 - 1.5. Investigate properties of sound propagation across seasons and sources
2. **Determine the acoustic repertory of seal (18 months)**
 - 2.1. Determine underwater vocalisations of seal (calls, burst, growl) / big data classification
 - 2.2. Ethoacoustics of seal emission within pollution, vessels, season / big data clustering
 - 2.3. Classify seal airborne / underwater vocalisations, pup/mum interaction
3. **Determine seal position and trajectories : big data tracking (6 months)**
 - 3.1. Seal 3D tracking
 - 3.2. Matching field model
 - 3.3. Monitoring variability of acoustic propagation in Baikal with seals signal

A. Generality

Title ; Big Data Passive Acoustic Baikal Observatory [B2O]

Organisation heading the project

DYNI Team, LSIS, Université de Toulon, av de l'université, 83130 La Garde, France

Administrative responsible

BOUTIN Eric, Président. Email : president@univ-tln.fr, boutin@univ-tln.fr, +33 (0)4 94 14 20 00

Scientific responsible

GLOTIN Hervé, Pi, Prof. UTLN LSIS, Email : herve.glotin@univ-tln.fr , +33 (0)4 94 14 28 24

Thema: biodiversity monitoring, big data, advanced acquisition, passive acoustics

Species: Baikal seal (*Pusa sibirica*), fishes *Comephorus baikalensis* and *Comephorus dybowskii*, and a copepod (*Epischura baikalensis*)

Area : Center of the Baikal lake, deepest area, -1600m deep, 30 km large

Duration : 01/01/2018- 31/12/2020 - 3 years

The main motivations for B2O are :

- Know the acoustic emission of the food chain: Soundscape of Baikal ecosystem,
- Few underwater seal vocalisation repertory exist,
- Baikal lake is an ideal setting for this task since many wild seals in a confined space,
- Collect and categorise the calls, compare with existing collections of other seals,
- Assess the population of the seal,
- Access the behaviour of the seal.

The first experience would be assumed by LSIS (DYNI) with Irkutsk collaboration to demonstrate the possibilities of installation of a long term bioacoustic monitoring in Baikal Lake.

B. Baikal lake and main elements of its trophic chain

Lake Baikal, the world's oldest and deepest freshwater lake, is situated in Russia in north of the Mongolian border. Some refer to Baikal as the country's "sacred sea". To scientists, it's "Russia's Galápagos": much of the fauna here is found nowhere else on Earth. Lake Baikal is the largest freshwater lake in the world, containing 22–23% of the world's fresh water (Schwarzenbach et al., 2003). At 636 Km long x 79 Km wide, Lake Baikal has the largest surface area of any freshwater lake in Asia, and is the deepest lake in the world at 1 642 m.



Fig: The Baikal lake at spring (May). B2O would be at the middle section (credit: c)

Concerning the water temperature, 3 parameters may change it: location, depth of the lake and seasons. The entire lake surface is covered by ice during 4–5 months, from early January to May–June. On average, the ice thickness is 0.5 m to 1.4 m. Its surface temperature in August is between 10 and 12 C°. Lake water is very clear (visibility = 40 m) due to high numbers of planktonic animals eating organic matters.

The pelagic food chain is simple, composed by phytoplankton (*Aulacoseira baicalensis*), mesozooplankton (*Epichura baicalensis*), macrozooplankton amphipod (*Macrohectopus*), fish (*Coregonus autumnalis migratorius* and four species of cottoid fishes), and finally Baikal seal (*Phoca sibirica*) (Yoshii et al 1999). More than half the species found in Lake Baikal are unique to this place (endemic species).

The diversity of Amphipoda in Baikal is really important (300 species with **95% of endemism**). These animals can measure until 90mm. Actually, we don't know the acoustic emissions of these

species. The Baikal lake is a threatened ecosystem, principally because of global warming, epidemics (1988 a disease wipe out between 5000 and 10 000 seals), increasing of tourism or chemical pollution. There are also some fisheries in the lake: 50 registered commercial fishing enterprises are enumerated in Baikal. Recreational fishing and ice-fishing are unrestricted in the lake (Brunello et al 2006). Different fisheries management is now implemented in Baikal for maintain the regulation of fishing (Matveyev, Samusenok 2015). They study the impact of fishing on species but not the impact of noise of fishing.

ISU (Irkutsk State University) try to develop a composite index reflecting the health status of aquatic ecosystems in Baikal. B2O could be efficient to improve this index. Increasing vessel traffic, fishing boat, excursion boat on the lake, could changes the phytoplankton composition and upset all this vulnerable and unique aquatic food chain. B2O acoustic monitoring will enable to know more about these species, and anticipate their damage, that could also directly results from noise pollution.

B.1 The Baikal seal (*Pusa sibirica*)

The Baikal seal (*Pusa sibirica*), is an endemic species to Lake Baikal. The Baikal seal is one of the smallest true seals and the only pinniped species that lives solely in freshwater (Randall et al 2002). Concerning its history, scientifics are not still sure of this provenance. But they suggest that they descent from the ringed seal *Phoca hispida* and that the species may have been isolated geographically for about 500 000 years (<http://www.pinnipeds.org>). Seal population is estimated at approximately 100 000 animals (Kutyrev et al 2008; a). Adult seal measures 1.4 m in length with a body mass from 63 to 70 Kg (Seal Conservation Society, 2007). The animal weight can vary during the year (lowest weight in summer) (Pastukhov 2007). There are a little sexual dimorphism (males are larger than female). So it's possible than acoustics emissions would be different between males and females. This hypothesis is also applicable for pup (up to 3.5 Kg, 70 cm; Pastukhov, 1971). For example, Thomas et al (1982) have described the repertory of vocalization of Weddell seal (*Leptonychotes weddelli*). They found 34 different calls (based on differences in frequency range, duration, repetition rate, number per series, presence or absence of harmonics, auxiliary sound usage, and contour). They have stated a distinct sex-related differences in vocalization usage. Seals males can produced more vocalizations than females.

Concerning the distribution of seal, they are present in all lake, but it depend of the season and environmental factors. Globally seasonal movement of seal is driven by ice more than food (Ivanov 1938). So in october, seals move towards bays, lagoons and river deltas, mostly along the eastern shore where ice forms and expands out into the lake. After this (January to May) they spread throughout the lake in deep water. Adults spends time in North of lake whereas immatures lives in south. Pups born in winter when baikal lake is frozen.

Since 2008, the Baikal seal has been classed as a Least Concern species on the IUCN Red List (IUCN Red List of Threatened Species). Principally due to chemical threats. In fact, introduce pollutants in ecosystem can have potential to impair fertility, diseases and immunocompetence (De Swart et al. 1995, Kannan et al. 2000). But the most serious future threat to the survival of the seal may be global noise pollution (anthropic activities), in addition to the climate warming, which has the potential to affect a closed cold-water ecosystem such as that of Lake Baikal (Burkanov 2016).



Fig : The Baikal Seal

Concerning reproduction, they are polygamous and territorial. Males mark the female's with a strong odor which can be smelled by another male if he approached. But it can be possible that males emit reproduction sound, to call females.

The main food source of seal is the golomyanka (cottoid oilfish, endemic to baikal lake). Particularly in winter and spring, 90% of its food is composed of *Golomyankas* (Pastukhov, 2007).

Diving patterns are not well documented but the mean of juveniles are between 10 m and 50 m depth, and for adult a maximum of 300 m (Kutyrev et al. 2006). During the day, dives are deepest, due to rise of their prey during the night. Times of depth are between 2 min and 10 min, but the longest recorded dives exceeded 40 min during winter (Stewart et al 1996).

Concerning acoustic communication of this species, we know anything. Based on some preliminary analyses we conducted on basic recordings available online (b), our team supposes and will use these facts :

- seal can emit some burst for echolocation (Fig. 1 & 2), at low frequency, for long range detections of about 300 m. This burst might be detectable at a range of 2 Km,
- some growls (Fig. 3) and vocalizations that might includes individual signatures, at least the size the animal (shift of the central frequency peak, inter-pulse interval variation,
- different calls are emitted between males and females,
- the previous hypothesis shall be applicable for pup - mother calls airborne and underwater,
- it can be possible that males emit reproduction sound, to call females.

Some pre-analysis of sea calls are given below. Acoustic monitoring of baikal seal is a central key to know the ecology, movement and communication of this animal. If we have access to these informations, it would be possible to elaborate program to protect them at short and long term.

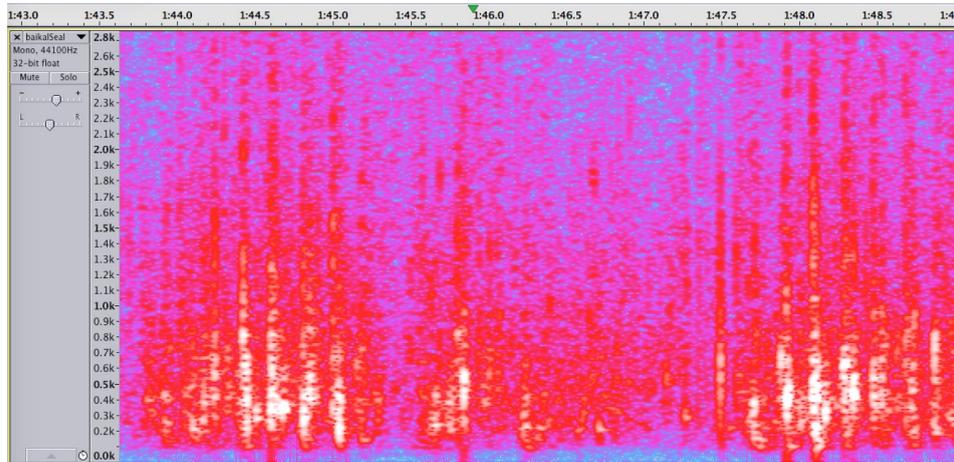


Fig.1 : Spectrogram (abscissa: seconde, ordinata: Hz) of a burst of a Baikal Seal (wav from **b**)

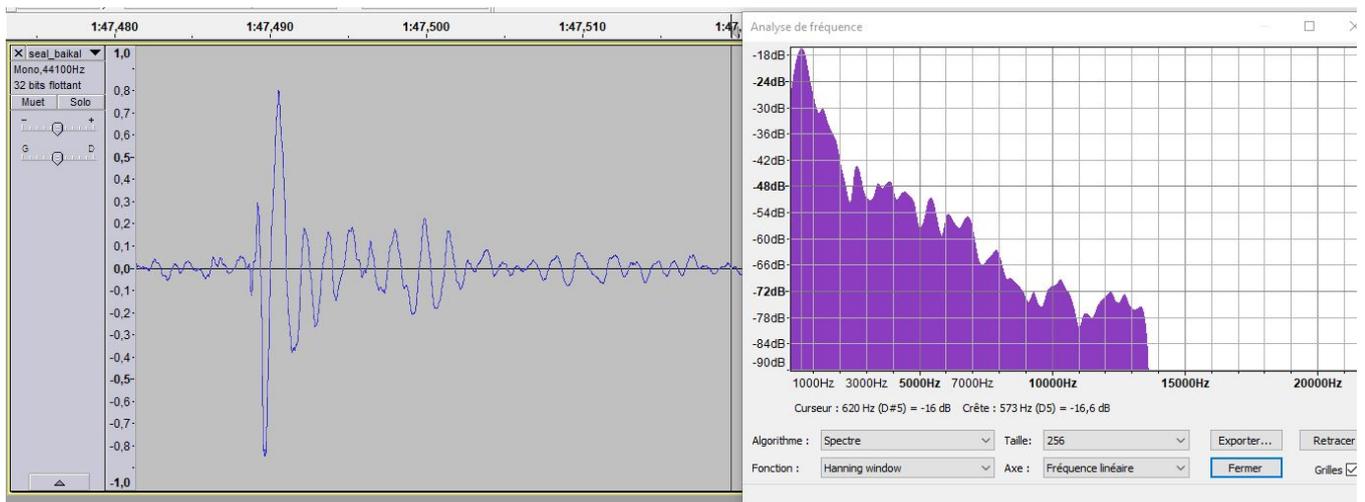


Fig.2: Representation of a Burst of Baikal Seal and its spectrum associate (recording from **b**). Duration of the burst = 20 ms. A frequency peak is visible at 2500 Hz. The burst is composed of two main pulsations that could depend of the size of the animal.

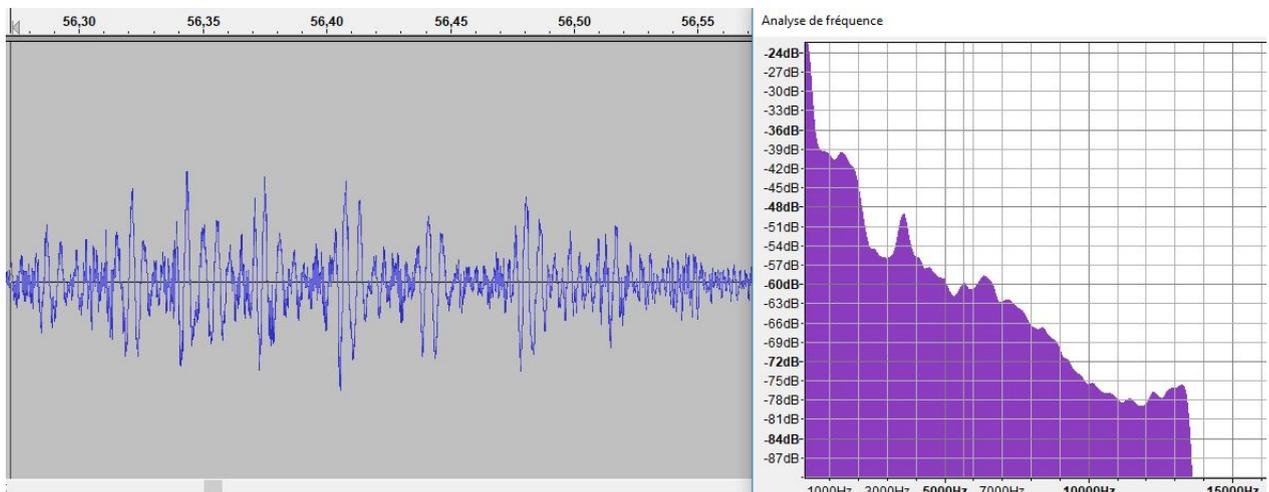


Fig.3: Representation of growls of Baikal Seal and its spectrum associate (recording from **b**). Duration of the growls 200 ms (ten times the duration of a burst Fig. 2). the frequency pick is around 3500 Hz.

B.2 The main food of the Baikal seal

The endemic Comephorus

Baikal oilfish or golomyankas are pelagic and also endemic to lake Baikal, is only genus in the family *Comephoridae*. Two species of golomyankas are present: *C. baikalensis* (21 cm) and *C. dybowskii* (16 cm), they have a translucent bodies (Froese et al 2012). They are composed by high lipid content, it for this reason that they are main food of seals. Golomyankas are present throughout the entire water column (from surface until 1 Km of deep), but they primarily occur deeper than 100m (Froese et al 2016). They move close to the surface (10-25m) during the night to feed (Burkanov, 2016). Golomyanka is the most populous fish in Baikal with a biomass of 150 thousand tons (70% fishes are *golomyankas*) (Froese et al 2016). We can see small group of fishes near the lake bottom (20 individuals). Concerning food, they feed the planktonic *Epischura baikalensis*, the amphipod crustacean *Macrohectopus branickii* and larvae of sculpins (Miyasaka et al 2006). ISU, particularly the Department of Vertebrate Zoology and Ecology already study the ecology of a number of endemic Baikal *Cottoidei* fish. We could correlate these abundance informations with the seal detections.



Fig : Endemic *Comephorus*

We don't know if this species can produce sound. But they are so numerous and they represent the largest concentration of fish in lake. At least their presence will produce specific sound diffraction of seals calls, or noise from the boat, or variations in time and frequency of the wave pattern of the calls of the seal.

Endemic *Epischura baikalensis*

Pelagic zooplankton of Lake Baikal is composed of a small number of species. *Epischura baikalensis* are the dominant pelagic zooplankton species (85 % of total biomass) (Penkova, 1997; Afanasyeva, 1998) This third species is also endemic to lake baikal. *Epischura baikalensis* is a species of copepod in family *Temoridae*, and measure up to 2 mm. They migrate annually through the water column, because they need low temperatures (5-10°C, dies above temperatures of 15°C). Biomass and abundance of this species vary seasonally and annually, with maximum abundance observed at the end of August and beginning of September. They plays the main role in filtering and purifying Baikal's water (Reid, 1996).



Fig : Endemic Epischura baikalensis

Again the acoustic quality of the water of the lake shall depend of the concentration and position of the plankton. We shall observe based on the quantity of measured light incoming in the lake, variation of the background noise, due to the variation of the concentration of the plankton in space and time, as we do observe in the ocean soundscape.

So, the aquatic food chain of lake Baikal is based on these four species. For this reason, the food web is very vulnerable, and if one element of the chain coming to disappear, all of lake ecosystem will be destroyed. Acoustic monitoring could give informations on the state of health and variability of this food chain.

C. Setting a permanent Passive Acoustic Observatory

The knowledge from this trophic chain is limited due to its seasonality and it is exclusively validated with visual observations. Observations are only performed during daytime, and they are too sparse to provide reliable conclusions. It would be interesting to add animal's velocity/trajectory, abundance data, from B2O systems. Assessing the effects and the propagation of underwater noise on seals also requires large databases that characterise animals' behaviour, movements and associated noise levels.

We would particularly be interested in the deepest area of the lake (-1600 m, middle of the lake, Fig. 4) in order to detect acoustic seal emissions during deep dives. The red plan in Fig. 4 represent the possible monitored area using our three passive acoustic stations.

First, we wish to place one station in the middle of the west shore of the lake (East station, Fig. 4), at -10m, with 40m of cable, simply connected to our aerial system with a battery car. The acoustic recorder has already been tested (it is produced by Toulon university for this research purpose by SMIoT cf [d](#)). This station would be in stereo (two hydrophones) in order to process source separation and estimation of the azimuthal movement of the seal.

Then we would complete these observations with another fixed stereo station on the West shore, at the other extremity of the transect in order to get a maximal view of this area of interest.

Another hydrophone station could complete the observatory, at winter time at a depth of -40 m, simply on the Baikal ice in the middle of the transect. At summer time, only several days of recording at the same place would be possible using a small boat and hydrophone and recorder than at winter.

We would produce 3D seal tracks. Our autonomous passive acoustic observatories are designed to produce tracks on large area, possibly of hundreds of seals each day. The revealed tracks and headings, speed of the seal will help to describe their behaviour in interactions with their preys and anthropophony. As the system works on diving animals, unseen at the surface, it provides a completely novel information. We will also track surfacing social groups if they are socializing and producing social sounds. In this case we manage to protect whole groups rather than individuals. This research is primordial in trying to understand the threats such as noise pollution.

This new information on how animals move in the 3D space to exploit habitat resources and to develop their social behaviours will provide completely new insights into their behaviour, and provide valuable information for their management. The detection of seals also provides information on the population structure and trend based on the size/age/sex of the detected animals.

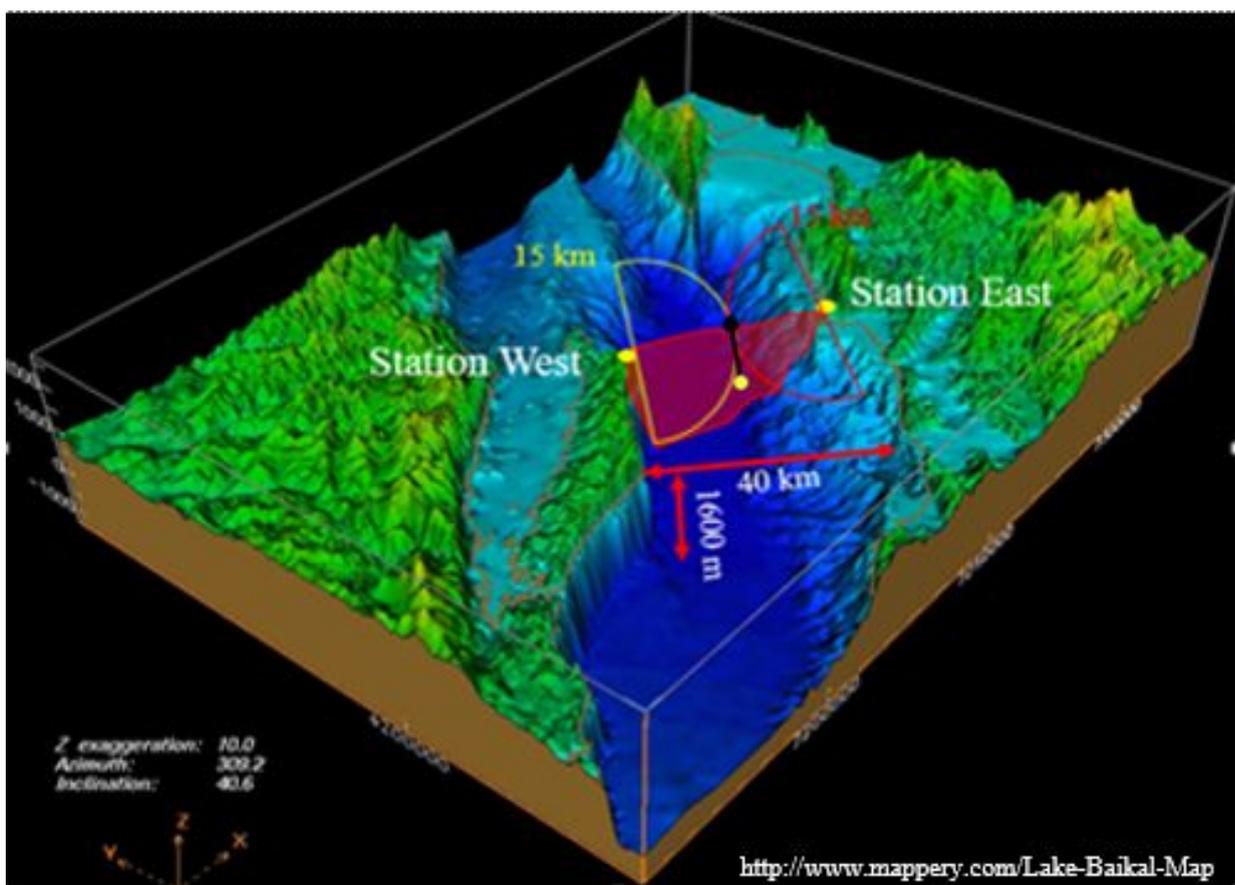


Fig. 4: B2O expected location. Yellow dots: positions on the shore of the West and East stations. Each station is a stereo recorder with hydrophones at -10m to avoid waves troubles. The station in the middle (black dash) will be deployed by cable at -40m, in summer from a boat at day time, and in winter from ice platform (one week 24/7).

The acoustic sensing approach will also permit the development of new approaches to lake environment management. Recent studies show that 50% of the ocean noise is generated by 15% of ships (Veirs 2017) and that in some coastal and other high-traffic areas, ship noise has reached levels that degrade habitat for endangered species marine wildlife (Hatch 2012, Erbe 2014, Viola 2017). According to Veirs (2016), ship noise can also have an impact on marine mammals' ability to echolocate their preys. Because the work of Veirs demonstrates that high frequency components of

ship noise interfere with echolocation, we may infer that it can also interfere with environment sensing and thus with ship detection.

Besides the primary tasks of the project, B2O will provide a new view of the Baikal soundscape, an area that is of primary importance for the whole region and for its endemic fauna. The analysis of the acoustic space will give a long term view of the combination of biological sources and of the anthropogenic noise sources, including far sources, such as pile driving activities taking place in a range of hundreds of Km (Sciacca 2016).

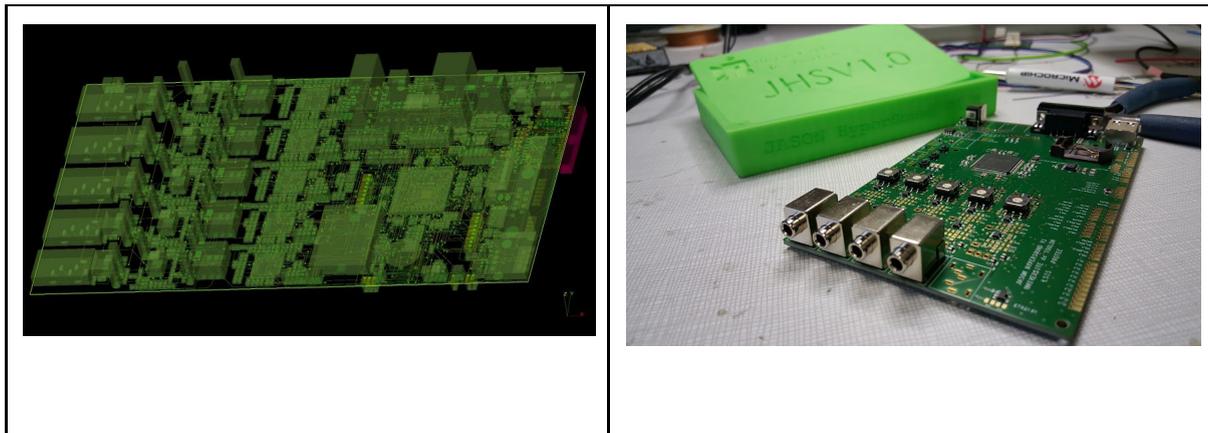
D. Methods

Objective 1: Characterise the underwater soundscape of Baikal lake

D1.1 Installation of robust acoustic & underwater/ice lux-meter stations

Our project is based on advanced scientific instrumentation to observe long term bioacoustic and light series. This instrumentation has been elaborated by our team at Toulon in the Information Numeric Prevention interdisciplinary Group and JASON project 2015-2016. It is now produced and sold at industrial quality for advanced research programs of environmental survey by the university Toulon technological platform SMIoT (d).

The recording card is the JASON high velocity audio card (Fig. 5), used to monitor up to 5 channels at 2 mHz sampling rate each. It is equipped by Cetacean research hydrophones and a simple battery, programmed to record N minutes each M minutes (M=0 for continuous recordings), 24/7, during 2 or 3 weeks depending of the battery type and the storage (usually a simple HDD 2 To).



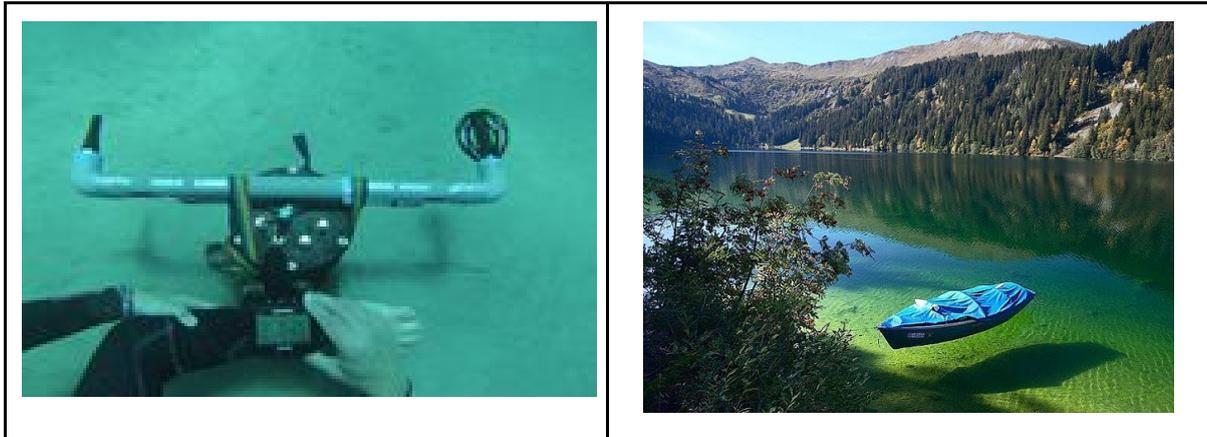


Fig 5: Top : the JASON HYPER SOUND DAQ version 4 x 2 mHz x 16 bits x low power = High Velocity + long autonomy. Bottom: Example of our autonomous stereo acoustic station, here placed at -10 m on Med. coast, for a full week, equipped of JASON recorder. It is also developed with 4 channels (called Blue4D). Bottom right: ex. of shore of the Baikal where will be placed the BLUE4D.

The second system is a luxmeter (Fig. 6), called qualilife-Light and developed by SMIoT to record variation of the light in the -40m the Baikal, joint to the central station. The activity of seals and other organisms shall depend on this parameter, and we will then correlate bioacoustic activities with it.

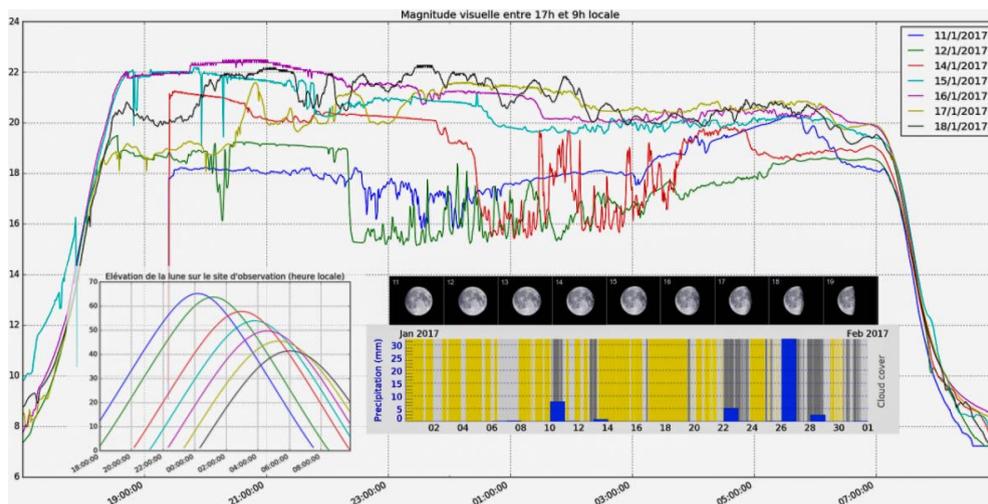


Fig 6: Qualilife-Light : result of high dynamic monitoring of nocturnal moon light during one week, with different weather conditions.

D1.2 Recordings long time series of lake soundscapes

Our approach is based on long term bioacoustic monitoring correlated with light and boat traffic. Detection of the seals would be optimized for RT operation (as in Glotin et al Boussole / DECAN / VAMOS Pelagos report 2017). Three dimensional or two dimensional tracking of the ecosystem will be processed on the whole corpus when at least 4 hydrophones (quadratic solver, Glotin 2009) are recording.

So for a long period (one year) we could describe the different sounds emitted from the ecosystem, correlation with luminance. Then, we will identify the sound sources : big data (8 Terabyte / year)

indexing (6 months). Finally, we will investigate properties of sound propagation across seasons and sources (6 months).

Objective 2: Determine the acoustic repertoire of seal

Once material was installed, and long records were effectuated, it will be possible to identified and classified sounds that we interest.

D2.1 Determine underwater emissions of seal : big data classification

The first part of acoustic study of baikal seal is to classify underwater emissions of animals (calls, burst, growl), it's the **big data classification on the To recorded by B2O**.

Some studies has already done different repertoires of seals emissions (Mirhaj et., al 2004). They found different types of calls (Fig. 7).

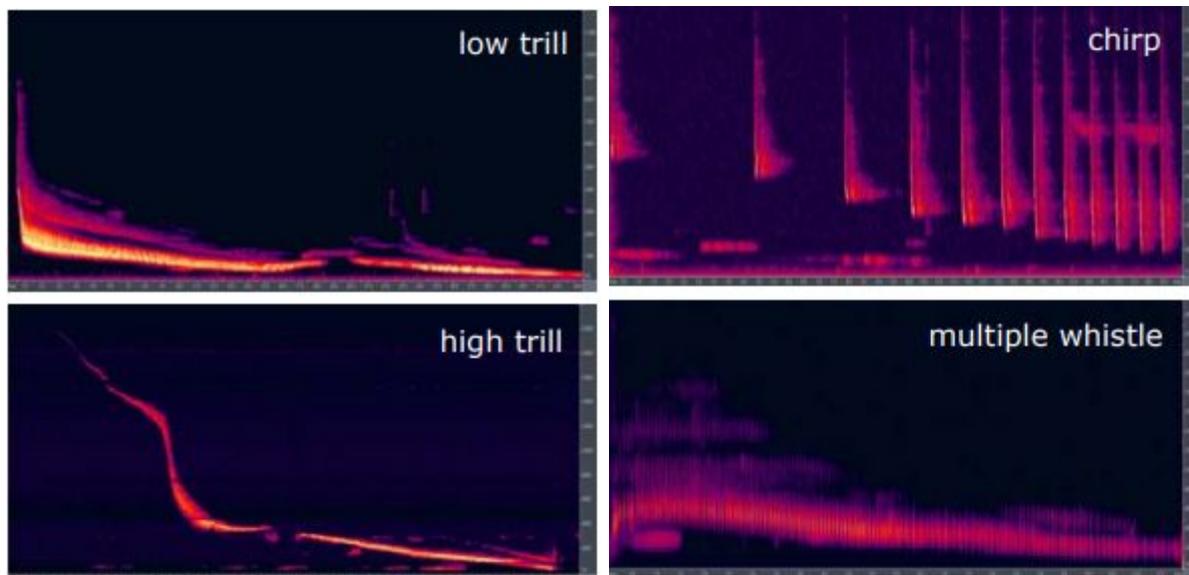


Fig. 7: Spectrograms of selected Weddell seal calls (Mirhaj et al 2004)

Our objective is to built a repertoire of baikal seal calls, and to compared theses calls with other species (Fig. 7). Abgrall et., al in 2003 have proved regional difference of vocalizations for Weddell seal (*Leptonychotes weddellii*). They found differences in the mesogeographic range and temporal range. But seals were separate from over 600 km. Baikal lake measure 636 km, so it is possible that there would be differences in vocalizations patterns through the lake. So this repertoires could depend on geographic positions.

Once these repertoires will be established, showing the different vocalization, it will be possible to correlate some of these emissions with external data such as pollution, seasons or boat traffic as presented in next section.

D2.2 Ethoacoustics: variations of seal emission according to external data

Poupart et al 2017 shown the feasibility to cluster acoustic patterns of dolphins and the consistency of this pattern linked to their behavior (Fig. 8). In this figure each point represent a whistle. Distance between points is really important: things being close together we can say that they are similar, and things being far apart we can confirm they are different. We can see two distinct clusters (0 and 1). Cluster 0 is composed only of Anthropogenic Pressure (AP). So There are variations of whistles structure, when behaviors changed, particularly with AP condition.

Our research should contribute to the evolution needed for the setting up of acoustic survey systems. These methods are therefore an excellent way for studying the dynamics of marine mammals populations, and to analyze impacts of humans on marine life. We will apply our model to monitor the behavior, ecology and trajectories of Seal.

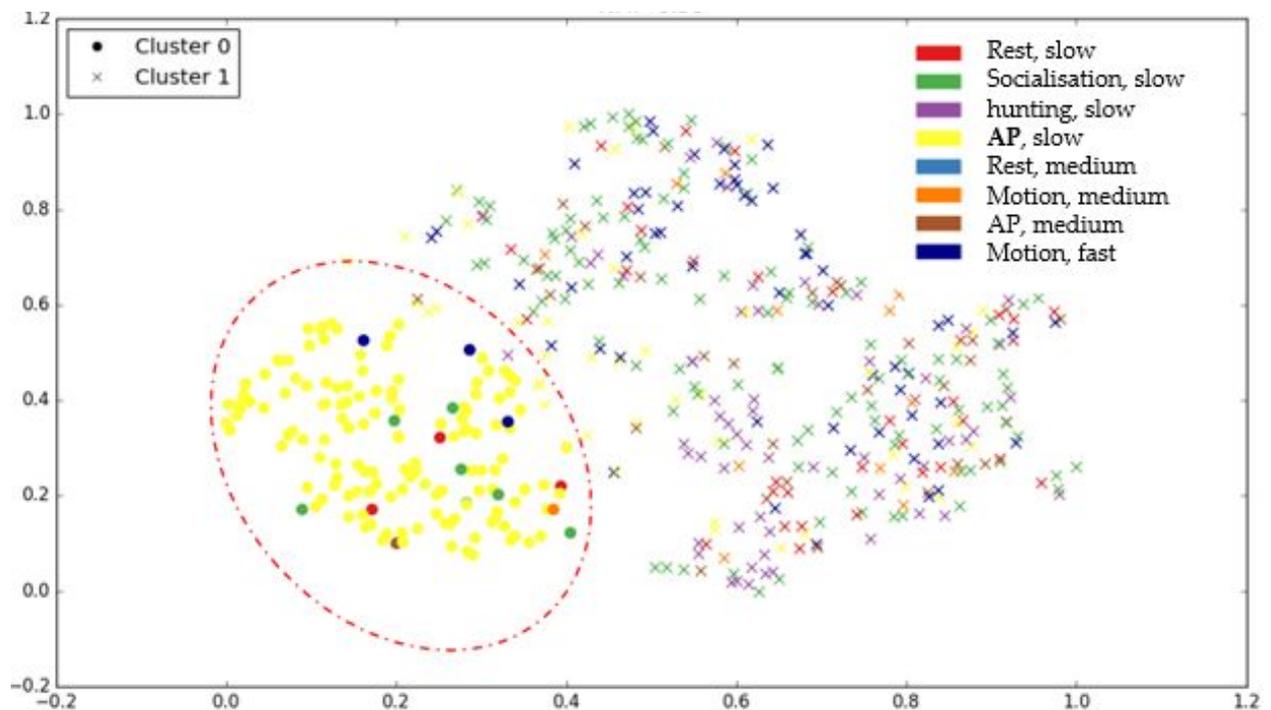


Fig 8: Visualizing dolphin Sa whistles in 2-dimensions with t-SNE as a function of velocity and behaviors (with 4 important features), according to BNP clustering. *AP=Anthropogenic Pressure

D2.3 Classify seal vocalizations in airborne environment

All pinnipeds can communicate vocally and visually, underwater or in airborne environment. In fact, there might be different airborne vocalizations. Stirling & Warneke (1971) have studied the structure and number of airborne vocalizations of the Australian fur seals. Four types of calls were identified:

- Pup attraction call given by adult females,
- Female-attraction call given by pups,
- High-intensity guttural threat given by adult males,
- Repetitive barking call given by adult males.

They found also differences between two species. Some studies proved individual signatures for pups vocalizations from grey seal (*Halichoerus grypus*) (McCulloch et al 1999).

It will be interesting to study seal vocalizations in airborne environment particularly after births (end of winter, on the ice). During this period animals are more present in North of lake because the longer winter keeps the ice frozen longer (preferable for pupping) (Pastukhov, 2007). So, we could install two stations in stereo (two hydrophones), with a camera. It will be possible to make correlation vocalizations and behaviours on the ice between mums and pups.

Objective 3: Determine seal positions / trajectories by big data

The third objective is to determine seal positions, in order to have new knowledge of the seal underwater behaviour in the lake. We could also explore correlation between seals positions with other characteristics of the lake such as temperatures, pollutions indices or preys quantities. The lake is a close environment so it is perfect setting for such study, given the possibility to install multiple passive acoustic systems with range overlap.

D3.1 Recordings and 3D monitor presence of Seal

Seal are obviously present all the year. The 2 shore recording stations, and the central station (Fig. 4) will allow large scale and long term passive acoustics monitoring of the seals, and possibly their prey. *Copepods* would also be monitored by passive acoustics at a row scale (to be confirmed).

The two recording stations (East and West) fixed on the shore will be, in the final system, each equipped of 4 hydrophones (4D) to solve the localisation of the source. The central station in summer time will be stereo to allow simple source separation. At winter time, we propose a quadri-hydrophone central station, fixed to the ice platform to get a high definition view of the movements of the fauna directly observed from the middle of the lake.

The complete large scale B2O observatory, composed of the two observatories on West and East stations, plus the middle observatory on the ice or on a boat, offers a large and continuous observation of fauna in a volume of nearly 40 km x 4 km x 1.6 km (the last dimension is depth).

The computed tracks will give insights into the seal behaviour according to their context including vessel noise / AIS traffic.

DYNI has the know how to track online by passive acoustics on stereo station (Fig. 8,9) and in 3D (Glotin et al. 2009 patent USA, EU, Glotin et al. 2014 patent on advanced tracking), with already proof of concept on astrophysic small array of hydrophones (Benard 2011), as shown in Fig. 10.

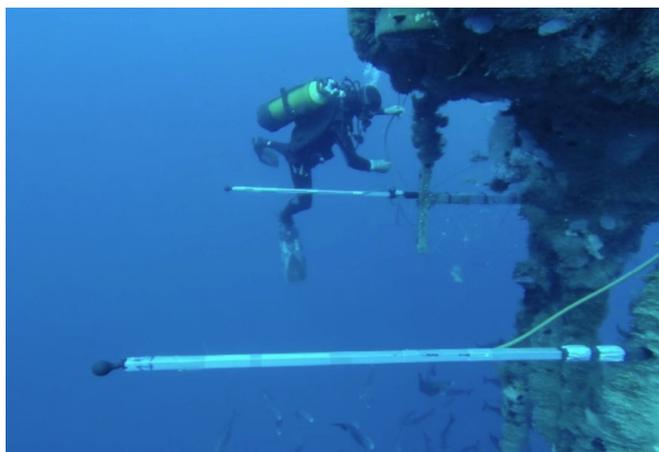


Fig. 8 : BOMBYX with stereo antenna pointed to South to observe the megafauna in front of Toulon (Med. Sea) (credit Dyni).

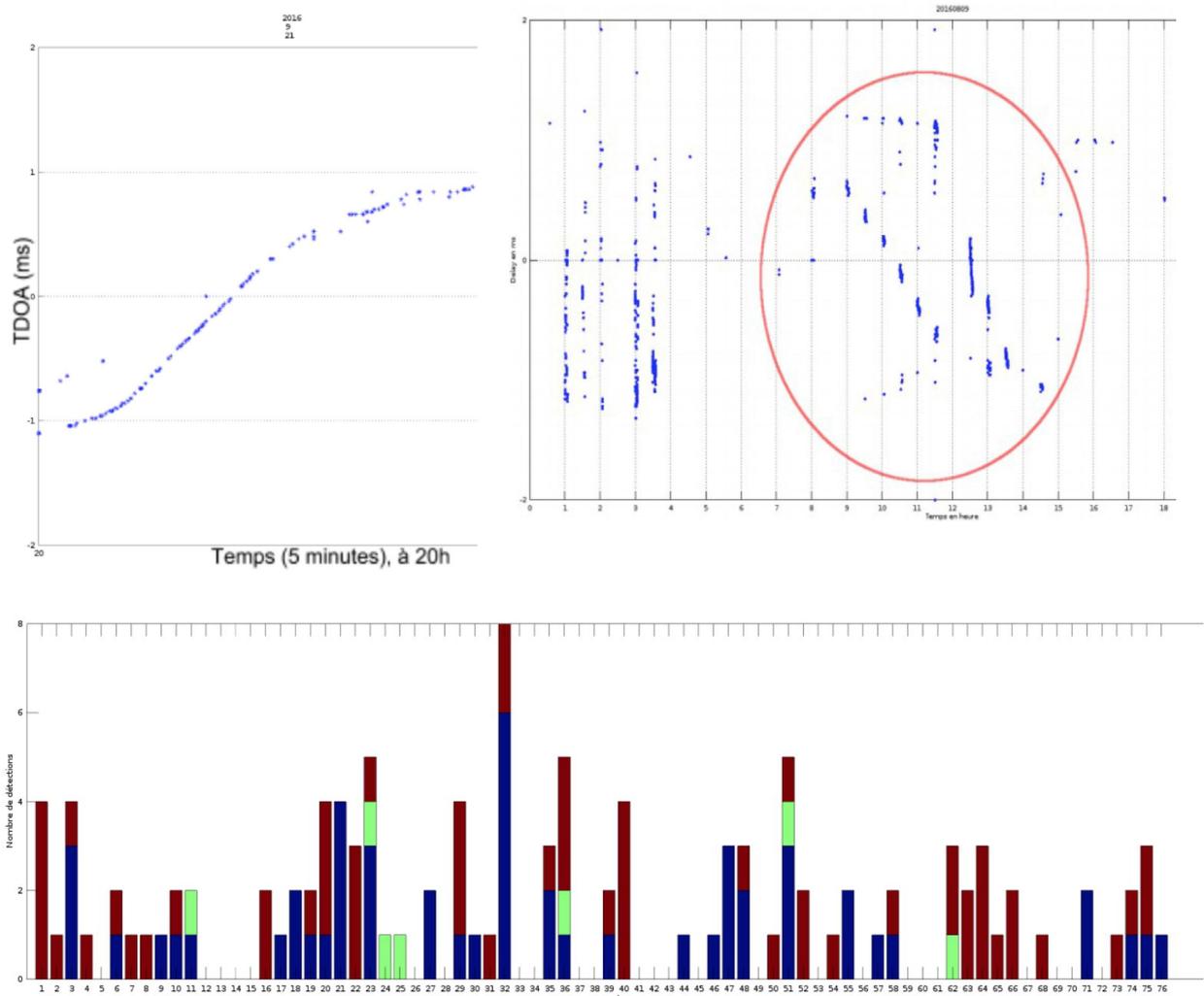
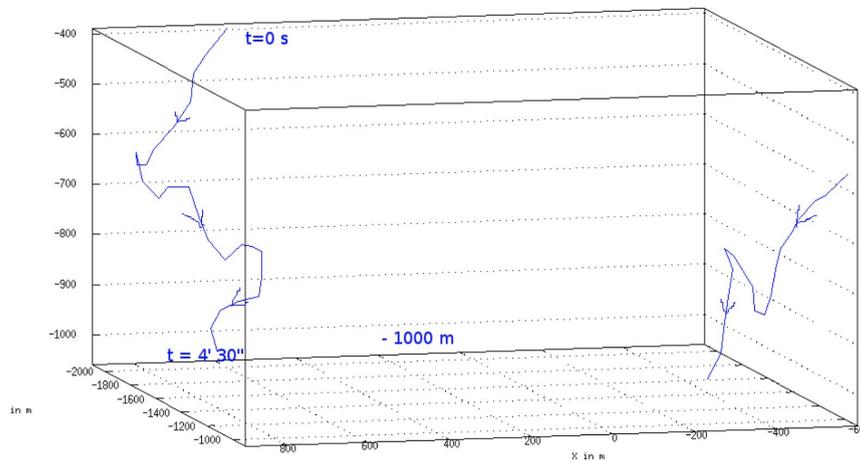


Fig. 9: Example of monitoring of Pm versus time from stereo BOMBYX. TopLeft : Time Delay Of Arrival showing acoustic detections of Pm going from East to West in 5 mn nearby BOMBYX the 21/09/2016. Top Right: Same, but long range Pm detections (inside circle), possibly 15 km, going from West to East in 7 hours the 6/08/2016. Bottom: Total Pm countings and directions in the 0-15 km range of BOMBYX, Red: from East to West, Blue inverse, Green: unknown, on 76 days of summer 2016 (Glotin et al., Vamos Pelagos 2016).

For the full 3D monitoring, we will need to complete the B2O array up to 4 hydrophones with JASON SMIoT (d) high velocity recorder (up to 5 x 500MHz Sampling Rate) to estimate the range, depth and azimuth of the seals swimming in a range of 1 to 3 km to a station.

LSIS results : 15 august 2005 15h00, Sicile Est :
2PC dive together from -400 m to -1000 m in 5 minutes



[Benard Glotin Applied Acoustics 2011]

Fig. 10: 3D Passive acoustic tracking of 2 Sperm whales diving together, computed from the 2 m aperture 4 hydrophones array of NEMO astrophysical obs. (placed 2km away from the whales) having similar geometry to MEUST (credit DYNI, Benard et al. 2011)

Moreover, we propose an airborne acoustic station in order to analyse the acoustic communication between pups and mums. This station will be in stereo, to allow separation of each source (males, females, pups).

D3.2 Matching field model

Time Delay of Arrival, and especially with small base lines, are difficult to use for tracking while for low frequencies. Thus, we propose to join our effort with another kind of method, based on matched field processing-type modelisation. This method is currently tested by our team in Chile for the follow up of large baleen whales emitting low-frequency songs (Patris et al 2017a,b). Ultimately, this method should enable us to recover at least the range of the seal with only one hydrophone.

D3.3 Monitoring acoustic propagation in Baikal and sound exposure

Some studies have already proved sound energy propagates further by tens of kilometres in shallow seas in winter and sound exposure experienced by seals is highly seasonally variable (Chen et al, 2017). These experiences were on grey seal in Celtic Sea (Fig. 11). Shapiro (2014) demonstrated the strong variability of sound propagation in the Celtic Sea due to strong seasonal variability in water column stratification. Their results showed large depth and seasonal differences in the noise level experienced by the seals, and reveal the actual noise exposure by the animals all along its dive.

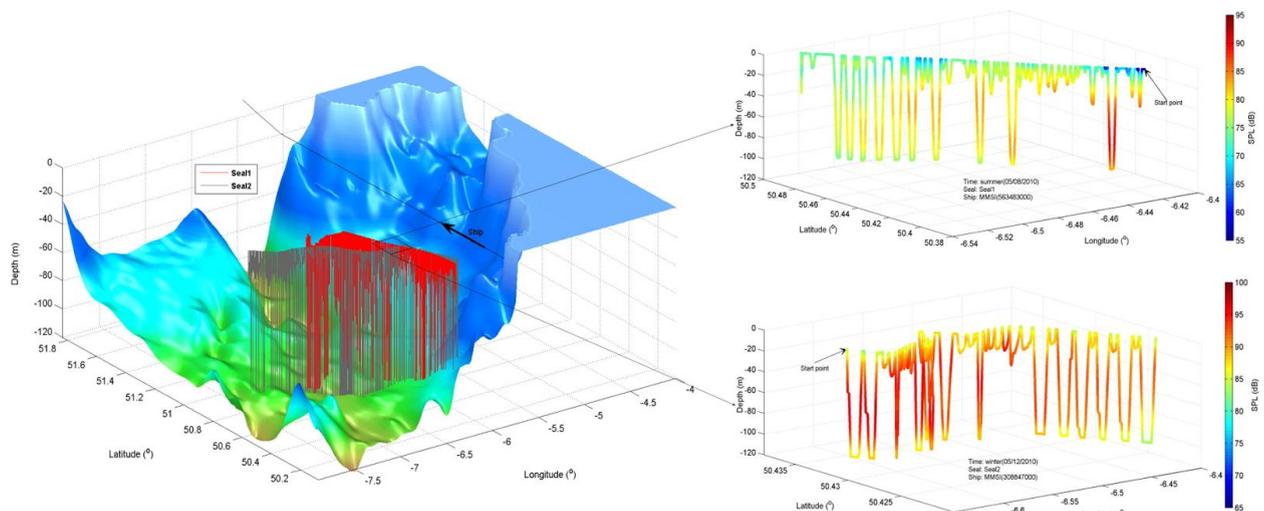


Figure 11 : Map of study area showing the sound exposure for two Celtic sea grey seal (1 and 2) according to seasons and depth in the Celtic Sea. Top right: sound in summer, Bottom right sound in winter. SPL: root-mean-square sound pressure levels = Sound exposure levels received by seals)(Chen et al, 2017).

The Baikal lake is an ideal location to investigate the use of oceanographical-referenced sound propagation models for assessing shipping noise exposure to seals and others animals. Climate and water temperatures vary considerably in function of seasons. Baikal seals are also an ideal species for the study of the acoustic propagations of this lake. In fact pinniped have hearing ranges from very low frequencies ~ 100 Hz (Kastak and Schusterman, 1998) to high frequencies ~ 30 kHz (Cunningham, Reichmuth, 2016).

But for now, acoustic repertoires of Baikal seal is still unknown. No study has investigated the behaviour of Caspian and Baikal seals and no vocalizations have been recorded (Van Opzeeland et.al, 2008). Actually just a recording exist. We have show on our pre-analysis different seal burst (echolocation) and some growl (Fig. 1, 2 and 3).

E. Logistics, Equipment, Schedule, Ressources

Logistics SMIoT UTLN (d) platform will increase BOMBYX observatory up to 5 hydrophones (AOT has been sent in this form) with its new technology co-developed with Parc National of Port Cros - France, DYNI and experienced by CIBRA team Italia Pavia univ.

Computation resources DYNI allows storage (200 To), GPU deep learning to run fast acoustic detectors and 3D tracking model, and also ethoacoustic models of cetaceans (Poupard et.al 2017) by unsupervised clustering.

Risk of the project The maintenances of B2O is a medium risk, as the proposed material allows robustness and efficiency.

Schedule / Big data effort = TOTAL per year = 9.2 To / year

months	seasons	Data acquisition		
		Record WEST station 4 hydro 500 kHz FE	Record EAST station 4 hydro 500 kHz FE	middle station 2 or 4 hydro 500 kHz FE
T ₁ =1 week in Jan or Feb 2018	winter, ice platform, allowing recording at middle station	1 To 1 week x 2 x 2 persons	1 To	1 To, 4 hydrophones on ice platform
T ₂ =2 weeks in May, June, July	spring / summer	2 To 2 week x 2 x 2 persons	2 To	100 Go, stereo from boat
T ₃ =1 week in Sept, Oct	autumn	1 To 1 week x 2 x 2 persons	1 To	100 Go, stereo from boat
Total	9.2 To / year	4To	4 To	1.2 To

Ressources

This project aims to open 2 workshops to disseminate the developed approaches and techniques as well as the findings of the proposed studies. We plan the production of 2 international publications.

A budget will have to be developed for a specific implementation of the proposal, however the LSIS DYNI team has availability for some of the equipment required by the project and has vast experience of more than 10 years in developing, installing and maintaining, and processing High Performance Computing (Deep learning) on passive acoustic monitoring observatories.

F. References

- Abgrall**, P., Terhune, J. M., Burton, H. R. (2003). Variation of Weddell seal (*Leptonychotes weddellii*) underwater vocalizations over mesogeographic ranges. *Aquatic Mammals*, 29(2), 268-277.
- Afanasyeva**, E. L., Life cycle of *Epischura baicalensis* Sars (Copepoda, Calanoida) in Lake Baikal. *Journal of marine systems*, 15(1), 351-357. 1998
- Bénard**, F., Glotin H., Giraudet P., Whale 3D monitoring using astrophysic NEMO ONDE two meters wide platform with state optimal filtering by Rao-Blackwell Monte Carlo data association, in : *Journal of Applied Acoustics*, Vol. 71 (2010), pp. 994-999, 2011
- Brunello**, A. J., Molotov, V. C., Dugherkhuu, B., Goldman, C., Khamaganova, E.,..., Lake Baikal. Experience and Lessons Learned. Tahoe-Baikal Institute, South Lake Tahoe, 2006
- Chen**, F., Shapiro, G. I., Bennett, K. A.,..., Embling, C. B. Shipping noise in a dynamic sea: a case study of grey seals in the Celtic Sea. *Marine pollution bulletin*, 114(1), 372-383, 2017
- Cunningham**, K. A., Reichmuth, C.,..., High-frequency hearing in seals and sea lions. *Hearing research*, 331, 83-91, 2016

- De Swart**, R. L., Harder, T. C., Ross, P. S.,..., Morbilliviruses and morbillivirus diseases of marine mammals. *Infectious Agents and Diseases* 4: 125-130, 1995
- Erbe**, C., Rob Williams, Doug Sandilands, Erin Ashe. Identifying Modeled Ship Noise Hotspots for Marine Mammals of Canadas Pacific Region. *PLoS ONE* 9, e89820, 2014
- Froese**, Rainer, and Daniel Pauly, eds., Species of *Comephorus* in FishBase, 2012
- Froese**, Rainer and Pauly, Daniel, eds., *Comephorus dybowskii* in FishBase, 2016
- Glotin**, H., Giraudet P., Ricard J.,...Visées aériennes de Mammifères marins jointes aux obs. acoustiques sous marines de Bombyx et Antares sur *Physeter m.*, Pelagos, 14-037-83400PC, 2017
- Glotin**, Bartcus, Roger, Chamroukhi, Patris, Juniper, Giraudet,..., Scaled Unsupervised Arctic Bioacoustics: Joint Narwhal Call and Click Train Monitoring, <http://sabiiod.org>, LSIS RR, 2015
- Glotin**, H., A. Mishchenko, P. Giraudet, Joint Dopler & Time-Delay of Arrival for efficient passive acoustic tracking - application to bioacoustics, Brevet INPI, 2014
- Glotin**, H., P. Giraudet, F. Bénard-Caudal, Multiple sources real-time tracking using transitivity constraints, Patent 2007/06162 FR, EU, USA 8638641, Australia 2008327744, New Zealand 606802, 2009-2012
- Hatch**, L.T., Christopher W. Clark,...., Quantifying Loss of Acoustic Communication Space for Right Whales in & around a U.S. N. Marine Sanctuary, *Cons. Biology* 26, 983–994 Wiley-Blackwell, 2012
- Ivanov**, T. M. Biology and harvest of Baikal seal. *Izv. Biol.-geograf. NII pri Vost.- Sib. gos. universitete. Irkutsk.- T.YIII. 1-2: 5-119*, 1938
- Kannan**, K., Blankenship, A. L., Jones, P.,..., Toxicity reference values for the toxic effects of polychlorinated biphenyls to aquatic mammals. *Human & Ecological Risk Assess.* 6: 181-201, 2000
- Kastak**, D., & Schusterman, R. J. Low-frequency amphibious hearing in pinnipeds: Methods, measurements, noise, and ecology. *J. of the Acoustical Society of America*, 103(4), 2216-2228. 1998
- Kutyrev**, I. A., Lamazhapova, G. P., Erofeeva, L. M., & Zhamsaranova, S. D. Comparison of microanatomical and cytological characteristics of mesenteric lymphatic node of adolescents and adult individuals of Baikal seal (*Pusa sibirica*). *ZOOLOGICHESKY*, 2006
- Kutyrev**, I. A., Pronin, N. M., Imikhelova, L. S., Petrov, E. A. and Kuzmina, E. A. Baikal nerpa. The passport and bibliography. Ulan-Ude, Russia *HURNAL*, 85(7), 886-892, 2008
- Matveyev**, A. N., & Samusenok, V. P. The fishes and fishery in Lake Baikal. *Aquatic Ecosystem Health & Management*, 18(2), 134-148, 2015
- McCulloch**, S., Pomeroy, P. P., & Slater, P. J., Individually distinctive pup vocalizations fail to prevent allo-suckling in grey seals. *Canadian Journal of Zoology*, 77(5), 716-723, 1999
- Mirhaj**, M., Plötz, J., Bornemann, H., Kindermann, L.,..., Underwater calls of Weddell seals in the Weddell sea, Antarctica, SCAR Open Science Conf., Antarctica & the Southern Ocean in the Global System, 25-31, 2004
- Miyasaka**, Dzyuba, Genkai-Kato..., Feeding ecology of two planktonic sculpins, *Comephorus baicalensis* & *Comephorus dybowskii*, in Lake Baikal. *Ichthyological Research* 53(4): 419-422, 2006
- Pastukhov**, V. D. Ecological characteristic of Baikal seal and features of its sustainable use. Avtoref. kand. diss. Irkutsk, 1971
- Pastukhov** Vladimir, D., The Face of Baikal - Nerpa, Baikal Web World. Retrieved 2007-09-27, 2007
- Patris**, J., Asch, M., Glotin H.,..., High performance modeling of the propagation of biological sounds in the ocean: new numerical tools in the study of cetaceans. in *Racket in the oceans : why underwater noise matters, how to manage it ?* École polytechnique, 2017
- Patris**, J., Malige, F., Komatitsch D., Asch, M., Glotin, H, Naval Acoustics, A New tool to model underwater propagation of whales songs, 2017
- Penkova** O.G. Zooplankton in the ecosystem of Lake Baikal, *Probl. conservation of biol. diversity of South. Sib., Mezhregion. scientific-practical. Conf., Kemerovo, May 19-22*, 1997
- Poupard**, M., Glotin, H. Automatic ethoacoustic data mining: applications on spotted dolphin whistles and humpback whale vocalizations. *DYNI LSIS Research Report*, 2017
- Randall** R. Reeves, Brent S. Stewart,... National Audubon Society Guide to the Marine Mammals of

the World, Alfred A. Knopf publishing, New York, 2002

Reid, J.W. *Epischura baikalensis*. The IUCN Red List of Threatened Species, 1996

Sciacca, V., Viola S.,..., Pavan G., Shipping noise and seismic airgun surveys in the Ionian Sea: Potential impact on Mediterranean fin whale. Proceedings of Meetings on Acoustics, 27 040010, 2016

Schwarzenbach, Rene P., Philip M. Gschwend, Dieter M. Imboden, Environmental Organic Chemistry (2 ed.), Wiley Interscience. p. 1052, 2003

Shapiro, G., Chen, F., Thain, R. The effect of ocean fronts on acoustic wave propagation in the Celtic Sea. Journal of Marine Systems, 139, 217-226, 2014

Stewart, B. S., Petrov, E. A., Baranov, E. A., Timonin, A., Ivanov, M., Seasonal movements & dive patterns of juvenile Baikal seals, *Phoca sibirica*. Marine Mammal Science 12(4): 528-542, 1996

Stirling, I., Warneke, R. M., Implications of a comparison of the airborne vocalizations & some aspects of the behaviour of the two Australian fur seals, *Arctocephalus* spp., on the evolution & present taxonomy of the genus, Australian Jour. of Zoology, 19(3), 227-241, 1971

Thomas, J., Pastukhov, V., Elsner, ..., *Phoca sibirica*. Mammalian Species 188: 1-6, 1982

Thomas, J. A., Kuechle, V. B., Quantitative analysis of Weddell seal underwater vocalizations at McMurdo Sound, Antarctica. The J. of the Acoustical Society of America, 72(6), 1730-1738, 1982

Van Opzeeland, I., Kindermann, L., ..., Insights into the acoustic behaviour of polar pinnipeds current knowledge & emerging techniques of study. Animal Behaviour: New Research, NY., 2008

Veirs, S., Veirs, V., Wood, J.D., Ship noise extends to frequencies used for echolocation by endangered killer whales. *PeerJ* 4, e1657, 2016

Veirs, S., Veirs, V., Williams, R., Jasny, M., Wood, J.D., A key to quieter seas: half of ship noise comes from 15% of the fleet, DOI: 10.22541/au.149039726.69540798, 2017

Viola, S., ..., Pavan G., ..., Continuous monitoring of noise levels in the Gulf of Catania-Western Ionian Sea. Study of correlation with ship traffic. Marine Pollution Bulletin, 2017

Yoshii, K., Melnik, N. G., Timoshkin, O., Stable isotope analyses of the pelagic food web in Lake Baikal. Limnology and Oceanography, 44(3), 502-511, 1999

- a. <http://www.iucnredlist.org>
- b. BBC, Nature Wildlife, Life_Animals_Mammals_Baikal seal
http://www.bbc.co.uk/nature/life/Baikal_Seal
- c. http://www.wikiwand.com/en/Lake_Baikal
- d. <http://smiot.univ-tln.fr>