Fish and chips

Fisheries research and acoustic tag technology

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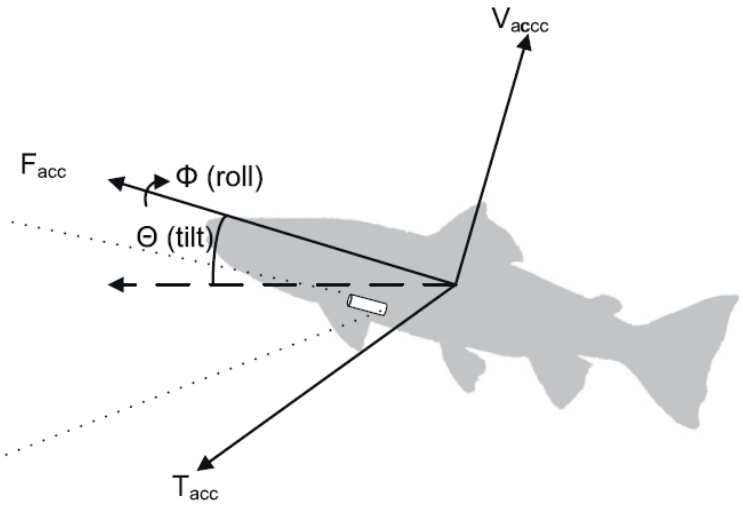
Contents

- Background
  - Relevance for fisheries science and management
- Electronic tag technology
  - Principles
  - Acoustic transmitter tags
  - Possibilities and limitations
- Case study
- Outlooks



The big picture

- The ocean and its biological resources have always played a fundamental role for human subsistence
- Escalating detrimental impacts on marine environments and resources now force us to seek more sustainable and scientifically founded management strategies

- Still, through most of history the ocean has represented an impenetrable and mysterious world for humans
- Knowledge about the ocean and fisheries must be increased in all respects
  - and the new enabling technologies will help us

Fisheries management

Sustainable management of fisheries resources requires deep knowledge of fish behaviour and how they interact with the complex and dynamic environment they live in

By increasing knowledge of what fish populations do, and relating this to the attributes of their habitat, we can start understand why they migrate and how they distribute in space and time.

Precise fisheries management depends on efficient methods for assessing the distribution and behaviour of fish

- Sampling surveys (trawls, acoustic etc.)
- Fishery landings
- Tagging
- ...

Understanding the mechanism of migration in the Atlantic salmon, one of the iconic species of the North Atlantic, has riddled us for centuries

Atlantic salmon (*Salmo salar*)

How far have we come?

1762: “Co-occurrence of moonfish in coastal salmon fisheries proves that moonfish are responsible for guiding salmon in from the sea.” (H. Strøm, Rector)

2014: Still speculating... (magnetism, olfaction, etc.)

Technology has only recently allowed us to start pursuing migration hypotheses for their validity.

Moonfish (*Lampris guttatus*)

Fish tags

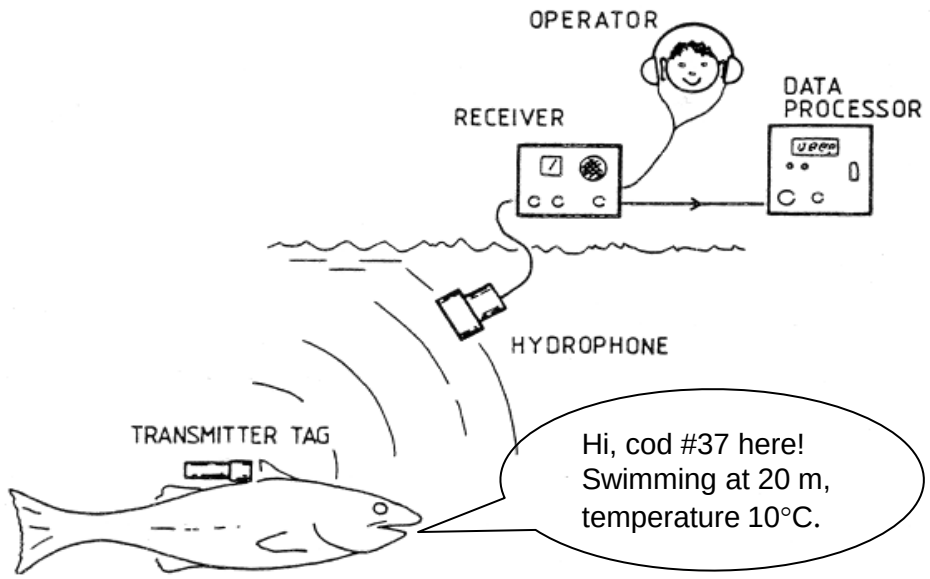
Tools for observing movement and behaviour of individual fish:

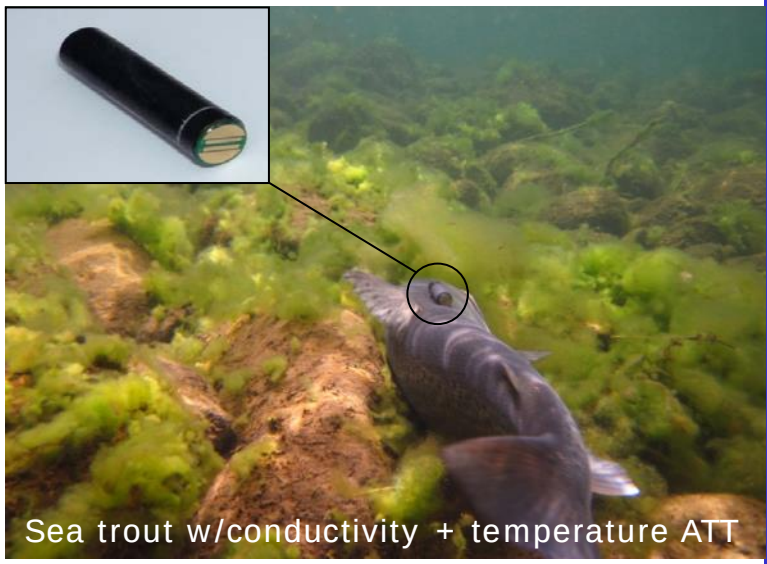
- Traditional mechanical markers

- Electronic tags (since ~1960s)
  - Transmitter/transponder tags
    - Radio
    - Acoustic
  - Data storage tags
  - Hybrids
    - (P)SAT, (pop-up) satellite archival tags
    - CHAT, comm. history archival tags

Acoustic transmitter tags (ATT)

- ATTs are fish telemetry tags in the traditional sense
- The only practical option for direct remote monitoring of individual fish in the marine environment



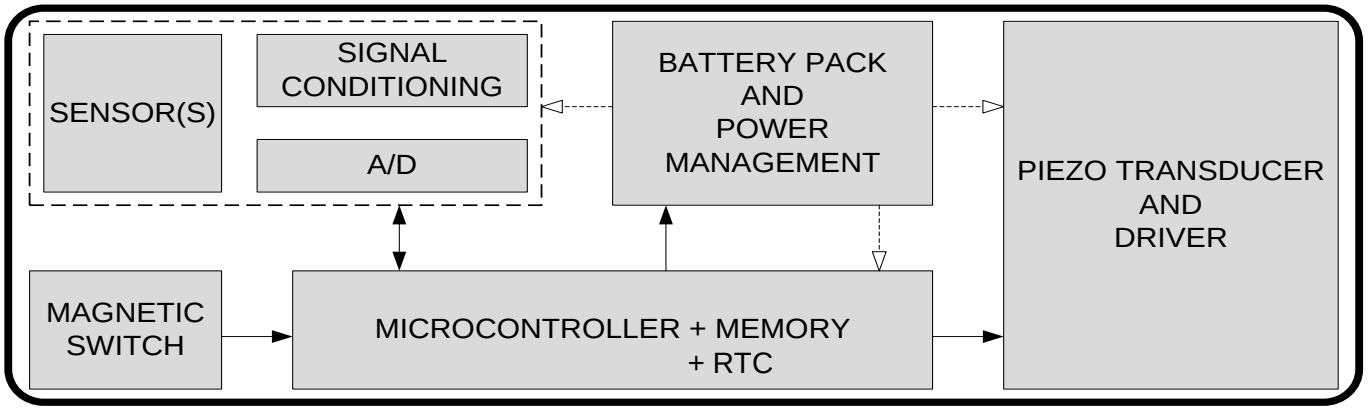

Sea trout w/conductivity + temperature ATT

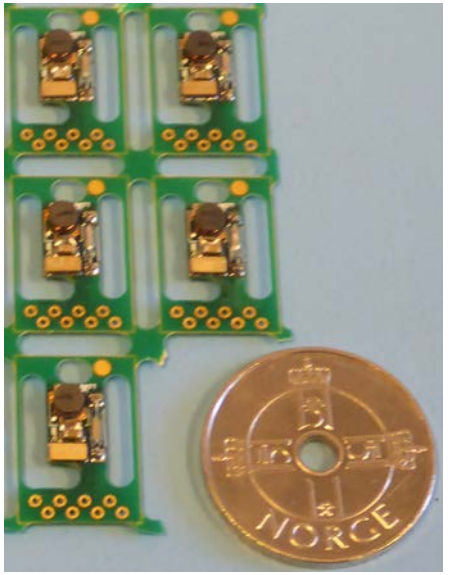
A wide variety of ATTs with different capabilities have been developed
- from simple analog “pingers” to advanced digital sensor transmitters

ATT components

Tubular transducer typically operated at 69 kHz

Typical tag components





ULP mixed-signal microcontoller + SMDs

Biologically inert pressure tight housing

Battery pack

ATT design considerations (the art of compromise)

«Ideal» tag requirements:

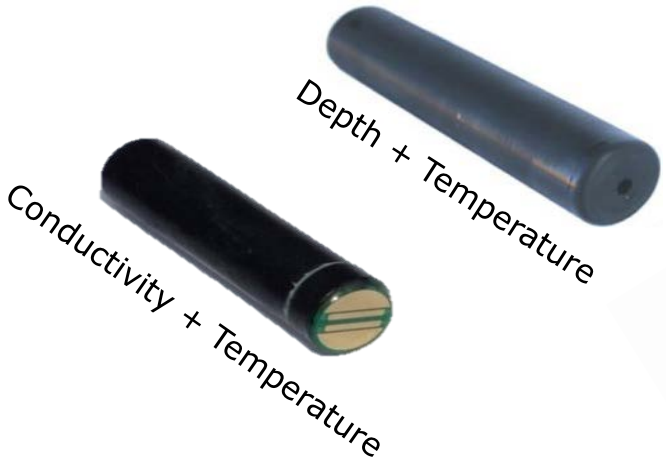
- Micro-sized
- Implantable by injection
- “Infinite” transmission range
- Mbit/s data rate
- “Infinite” tag life -
  consume no power
  (or harvest energy from envir.)
- “All” sensors available
- No limitations on tag coexistence
- Cheap

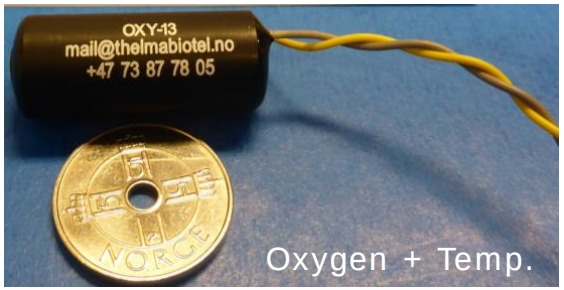
Practical world:

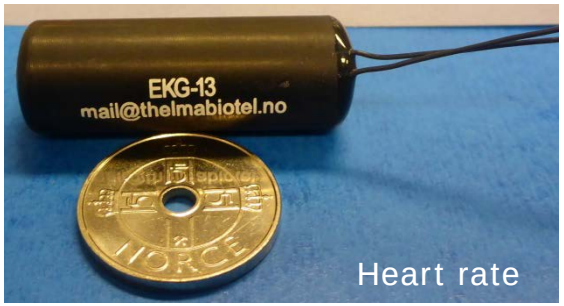
- Physical laws impose lower bounds on battery and transducer size
- Longer range -> more power -> larger battery -> larger tag
- Longer range -> lower frequency -> larger transducer -> larger tag
- High data rate -> more complexity and more power -> larger tag
- More sensors -> more complexity and more power ->larger and more expensive tag

ATT – sensor tags

- Integration of sensors with ATTs will increase the flow of useful information from the telemetered fish:
  - Pressure sensor -> swimming depth, vertical behaviour
  - Temperature sensor -> ambient temperature, thermal habitat
  - Accelerometers -> motion, activity pattern, posture
  - Conductivity cell -> salinity, water chemistry
  - ECG/EMG -> activity, stress, bioenegetics
  - Oxygen -> water quality





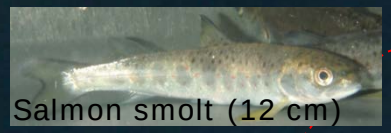


ATT receivers

- Automatic monitoring receivers
  - Mostly single frequency 69 kHz
  - Stand-alone operation
  - Deployment time ≥ 1 year (ultra low power consumption)
  - Cost efficient, but static
- Portable manual receivers
  - Multi-frequency, flexible
  - Manual tracking costly/exhausting
- Multi-receiver systems for 2D/3D tracking
- Autonomous mobile and intelligent receiver platforms
  - Next leap forward?

Automatic monitoring receivers in a typical “array” configuration.

Salmon smolt seaward migration study (Inner Sognefjord, Norway).



1 km

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Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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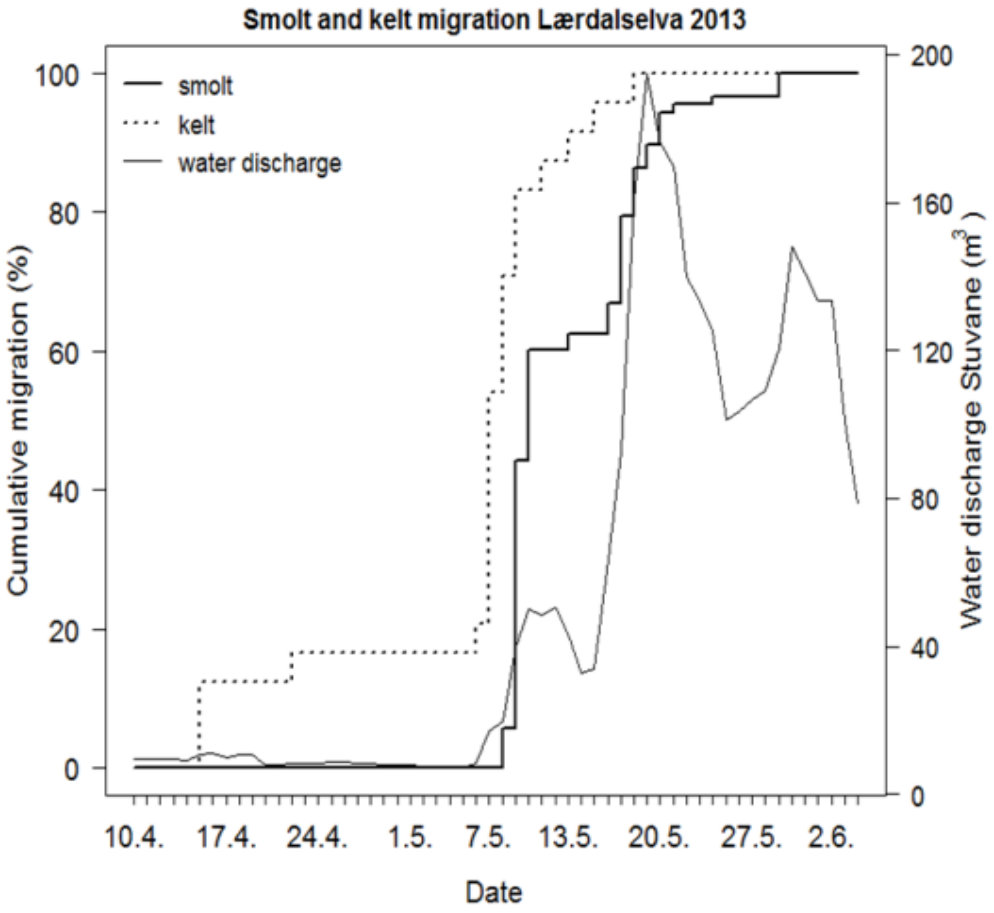
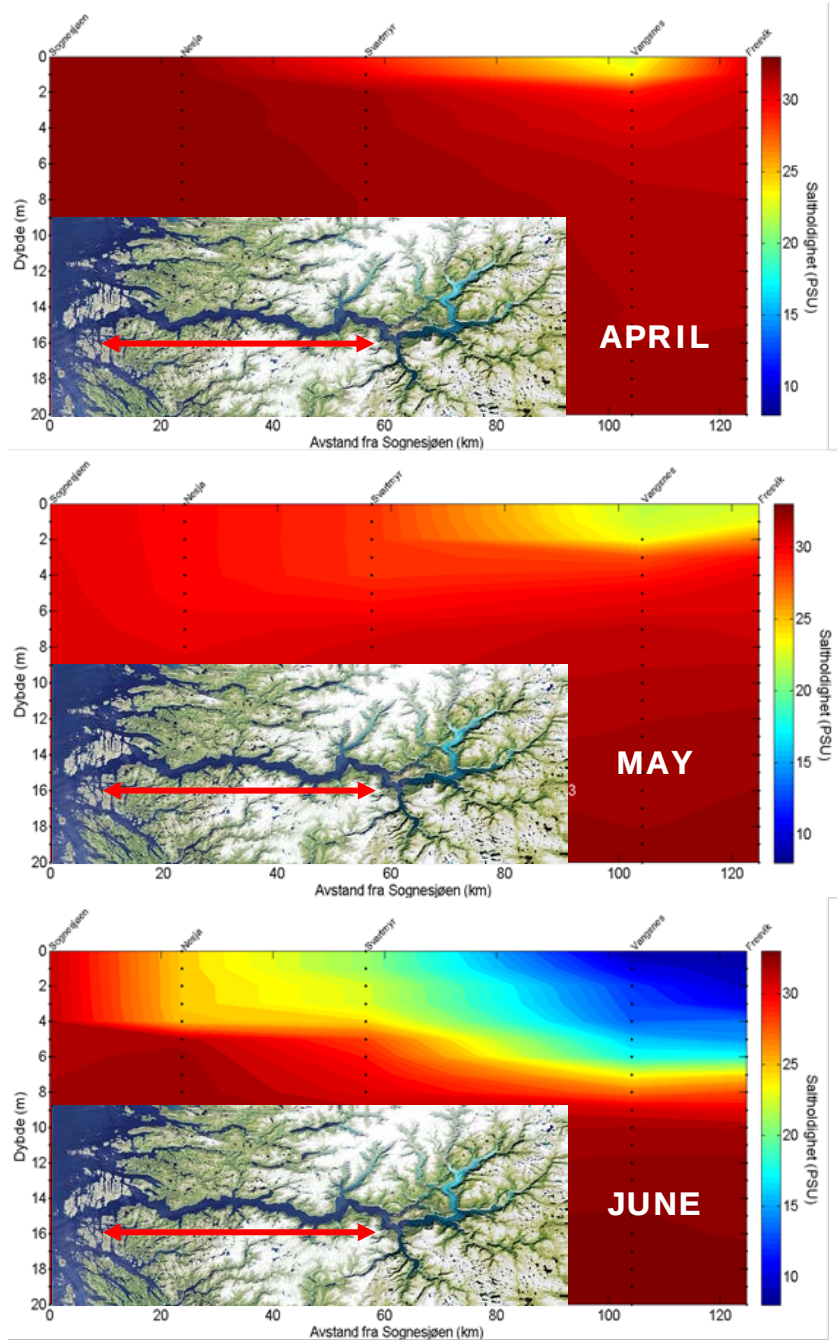
Google earth

Results show that salmon smolts seem to migrate in the very “front” of the brackish water layer developing at the fjord surface during spring (river run-off)

Indicate delicate balance with respect to seaward migration timing and infestation pressure from the halophile sea lice produced in the coastal salmon farms

Important management input with respect to timing and extent of salmon farm de-licing



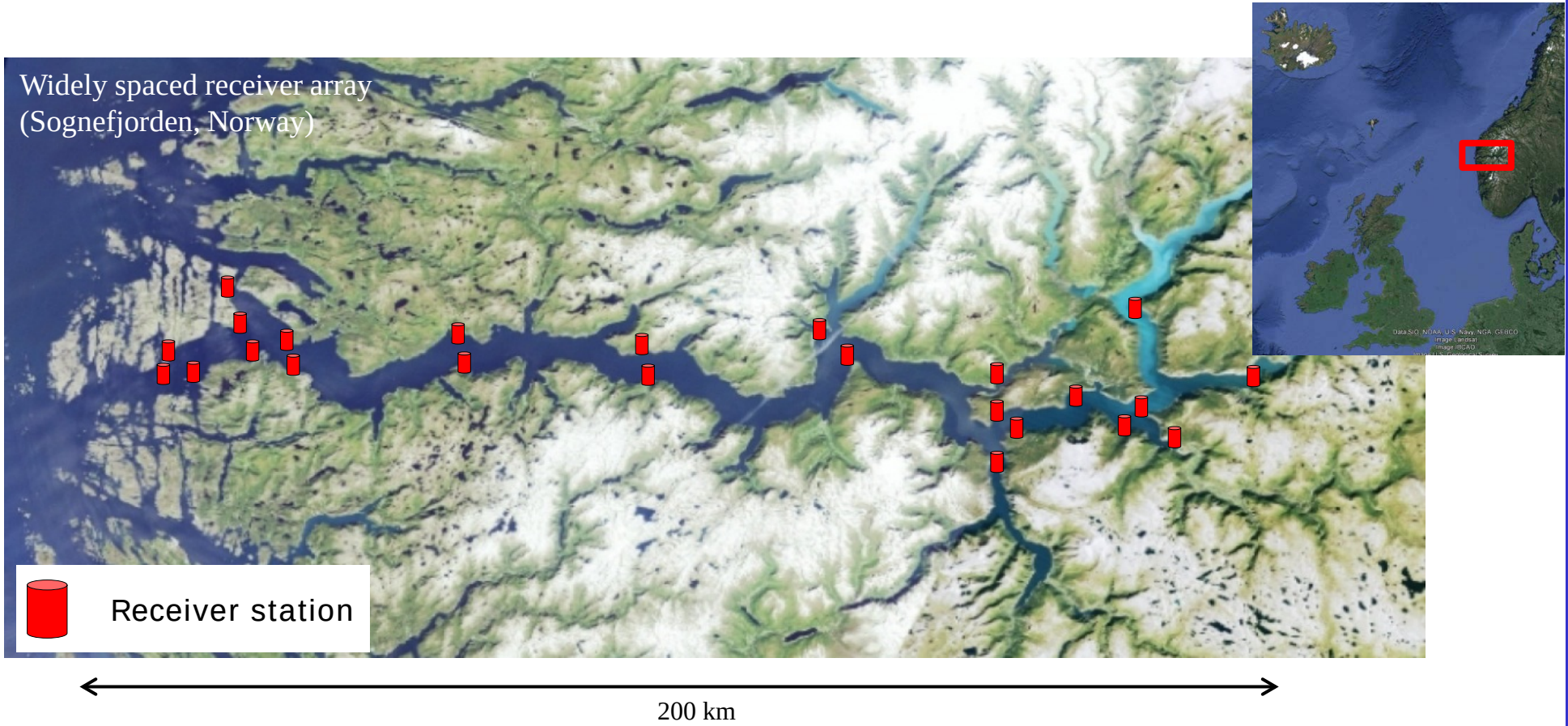


Figur 1. Lengdesnitt over vertikalprofil av salinitet innover Sognefjorden frå Sognesjøen (stasjon 1) medio april, mai og juni 2013. Stasjonar (1-5) angitt.

Receiver arrays

Useful, but…

- Practical limitations on array resolution -> holes in data set
- Low bandwidth of acoustic link limits data capture
- Sensor data reflect situation only around receiver (no history)
- Manual tracking prohibitively expensive



Outlooks

- Progress in diversity, capability and miniaturization of ATTs will continue
  - Allowing studies of even smaller fish, for longer periods of time, and with more useful information telemetered from the fish
  - Powered by extreme progress in the portable ULP electronics embedded systems (mobiles, IoT etc.), sensor/MEMS, and material science industries
  - Batteries and transducers may impose physical limits on what's possible
- Increased computing efficiency in processors will allow implementation of more sophisticated acoustic communication algorithms in both receivers and ATT (DST and ATT fusion)
- And perhaps the most interesting possibility: Integration of ATT receivers with robotic platforms such as AUVs and ASVs
  - Complementary to receiver arrays
  - Concurrent high resolution/capacity environmental and habitat monitoring
  - New possibilities/intelligent monitoring – "follow that fish"
  - Cost efficient