Electric and magnetic senses in marine animals, and potential effects of electromagnetic surveys

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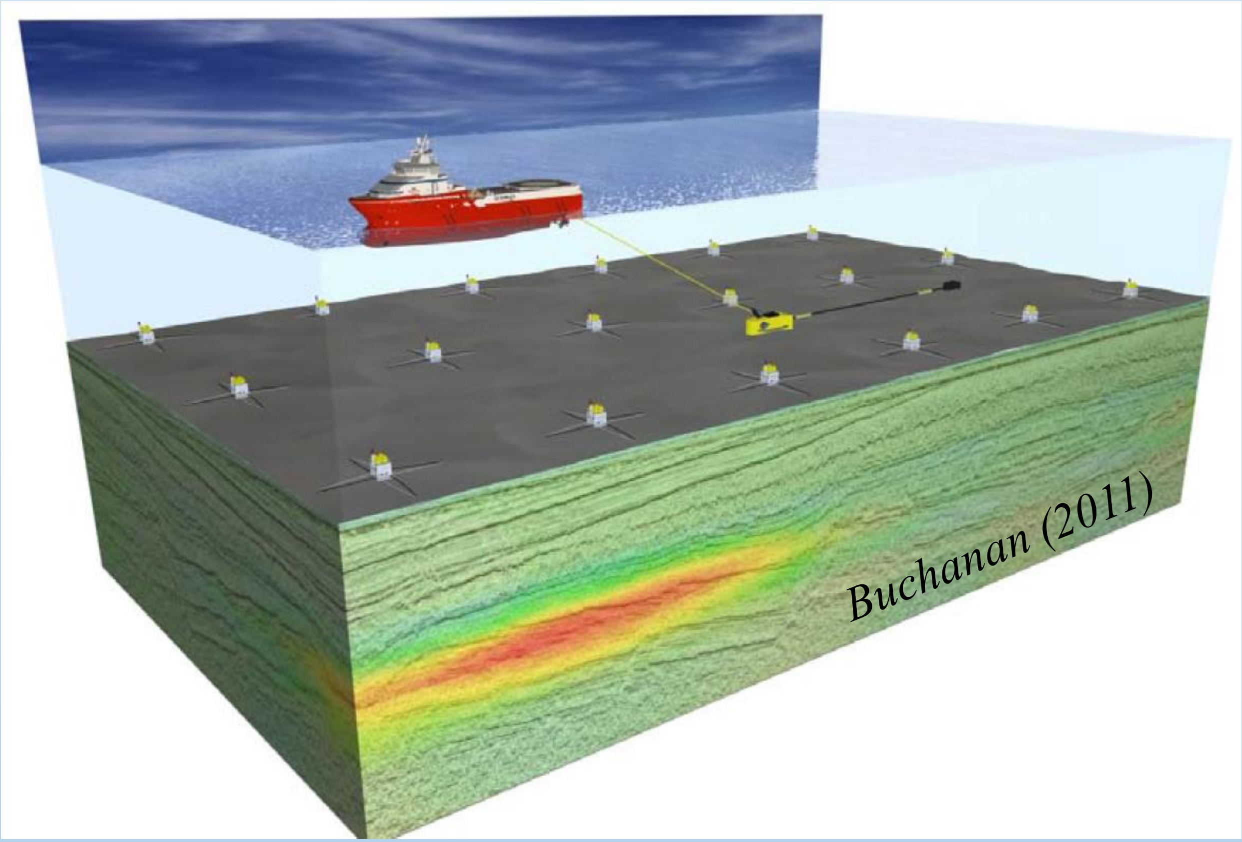
Photo: NOAA

Electromagnetic surveys

- Electromagnetism is used to map petroleum deposits under the sea bed.



Electromagnetic surveys

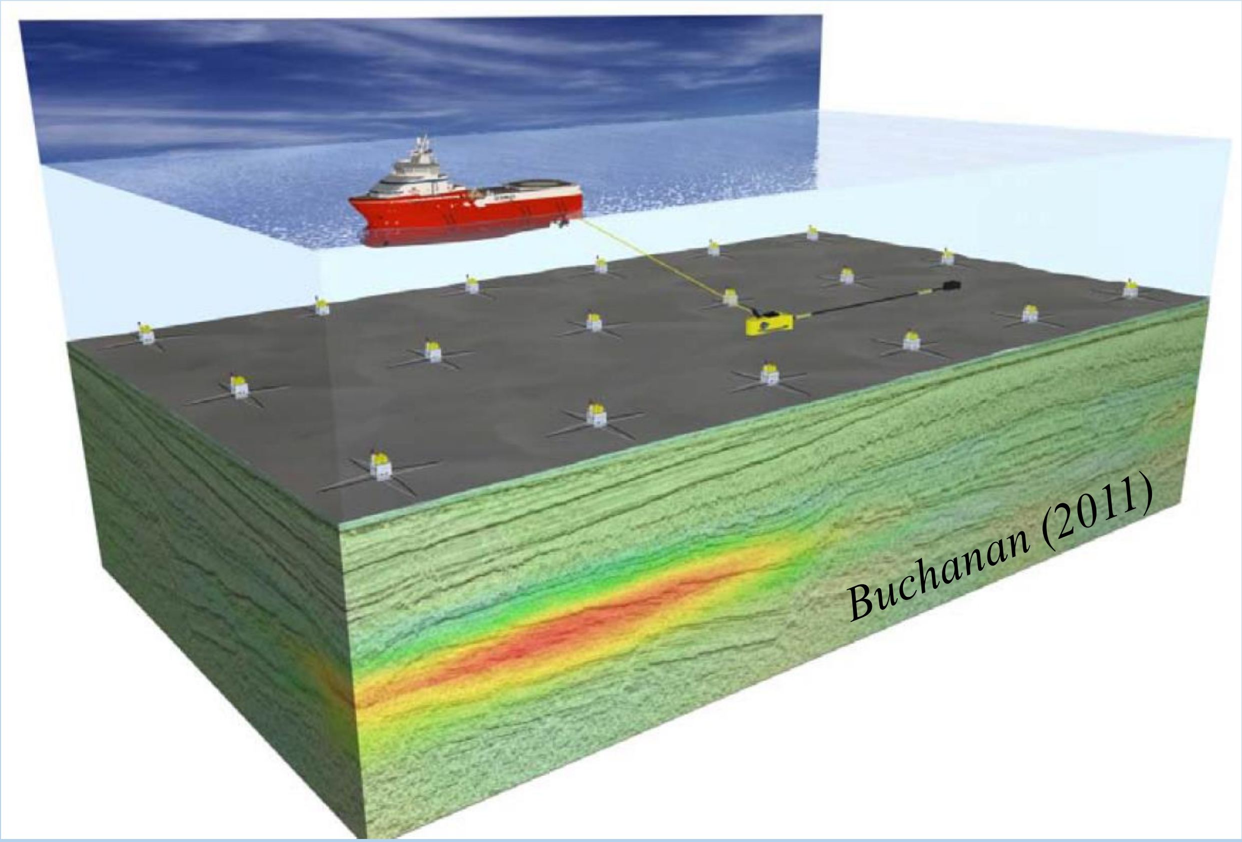
Electric current at the source

-> magnetic field

-> secondary electric field in the sea floor

-> secondary magnetic fields in the sea floor

-> Characteristics of the magnetic fields depend on the electric properties of the ground and are used to model petroleum deposits in the ground

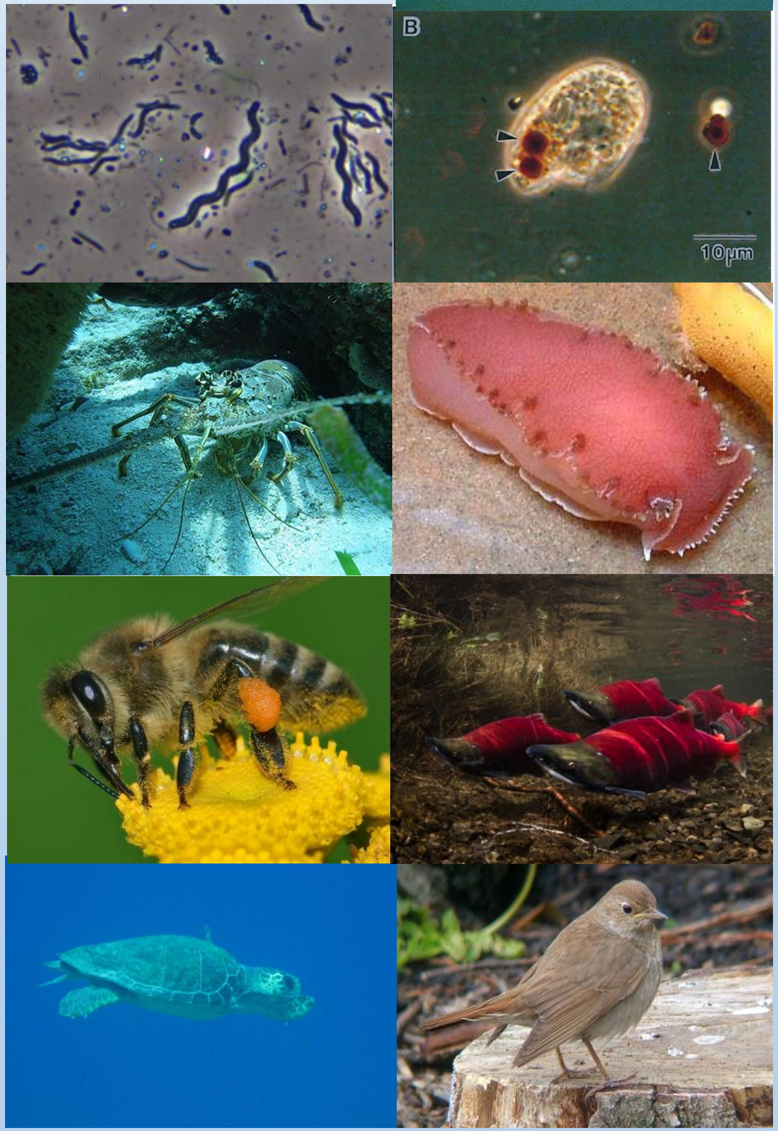


Effects of magnetic disturbances on animal behavior

NO PUBLISHED STUDIES ON EFFECTS OF ELECTROMAGNETIC SURVEYS ON ANIMAL BEHAVIOR?

- Natural electromagnetic fields
- Electric and magnetic senses in marine animals
- Studies on effects of disturbances (natural and antropogenic)

Magnetic fields and animals



- Great variety of organism respond to geomagnetic cues: bacteria, protists, gastropods, crustaceans, insects, fish, sea turtles, birds, whales.
- Many animals seem to rely on the earths magnetic field for orientation.

Bazylinski et al. 2000 (protist); NPS (lobster); Australian Museum (nudibranch); Andreas Trepte (bee); Jonny Armstrong / salmon-net.org; MPF (nightingale): NOAA (whale)

Earth’s magnetic field

- Direction
- Strength / intensity
- Inclination

- Predictable
- Local anomolies

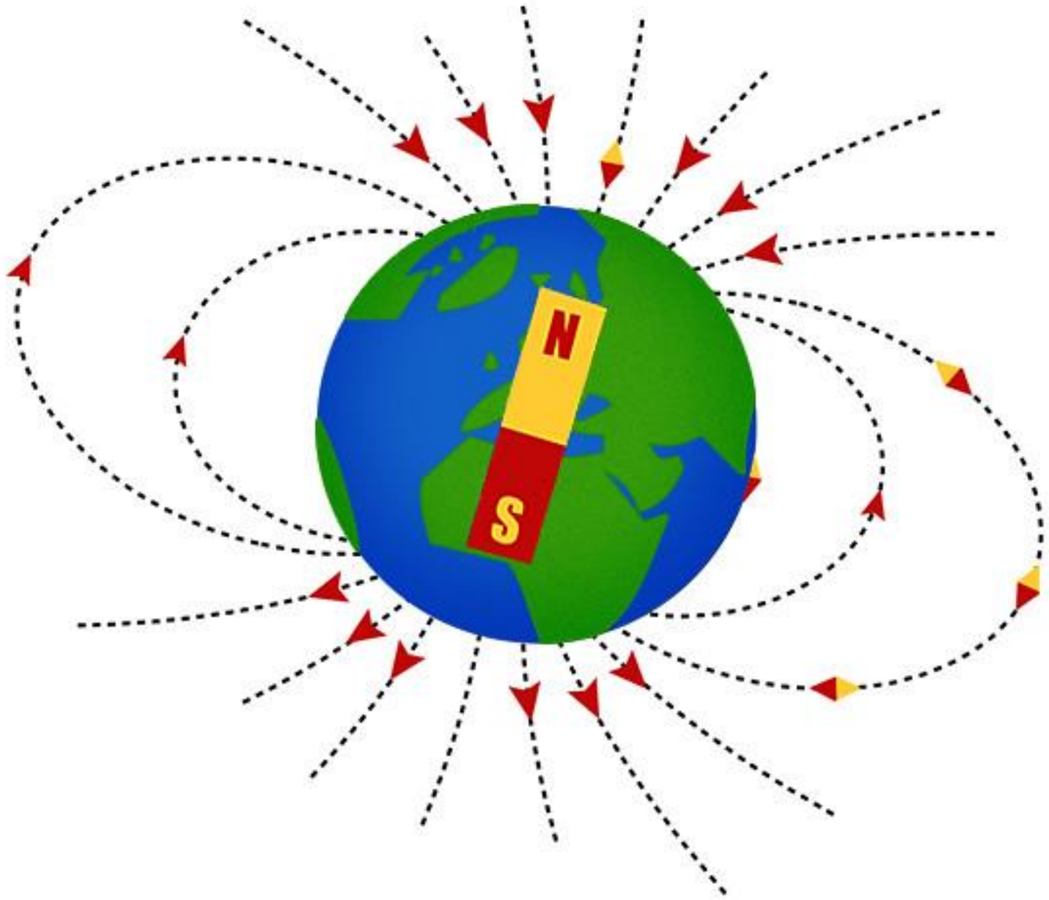
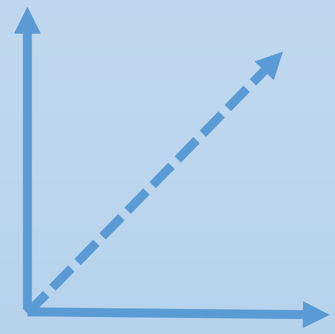


Image: Zappys Technology Solutions

Earth’s magnetic field

Total intensity

- 30 000 – 60 000 nT
- 2-5 nT/km



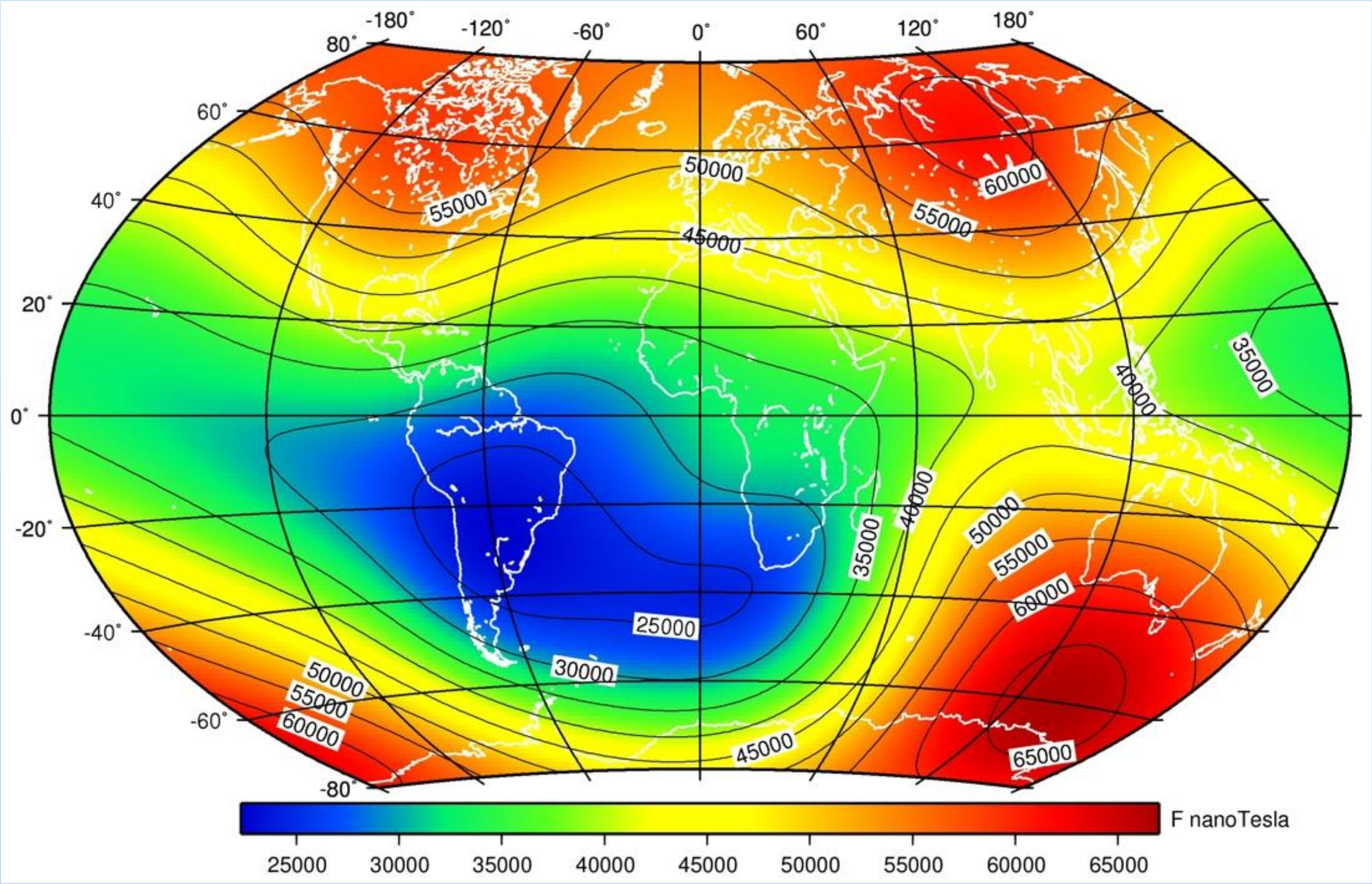


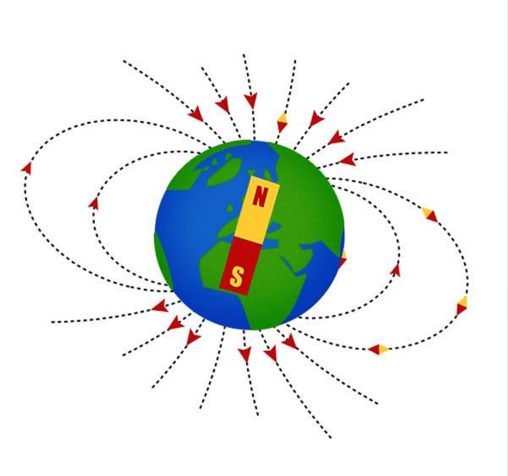
Image: Brittish Geological Survey

Earth’s magnetic field

Inclination

- 0-90°

- 0.01°/km



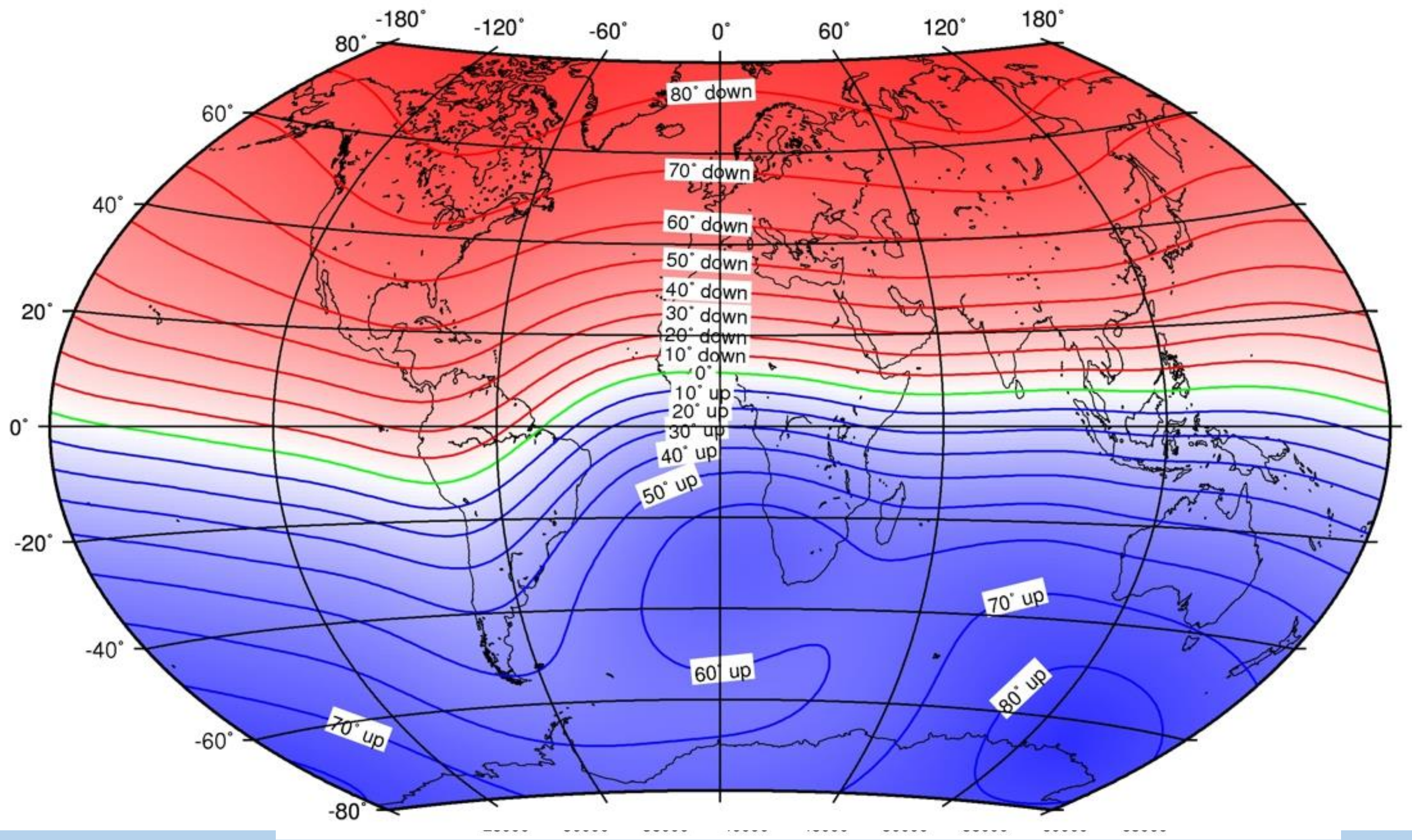


Image: Brittish Geological Survey

Long distance migration

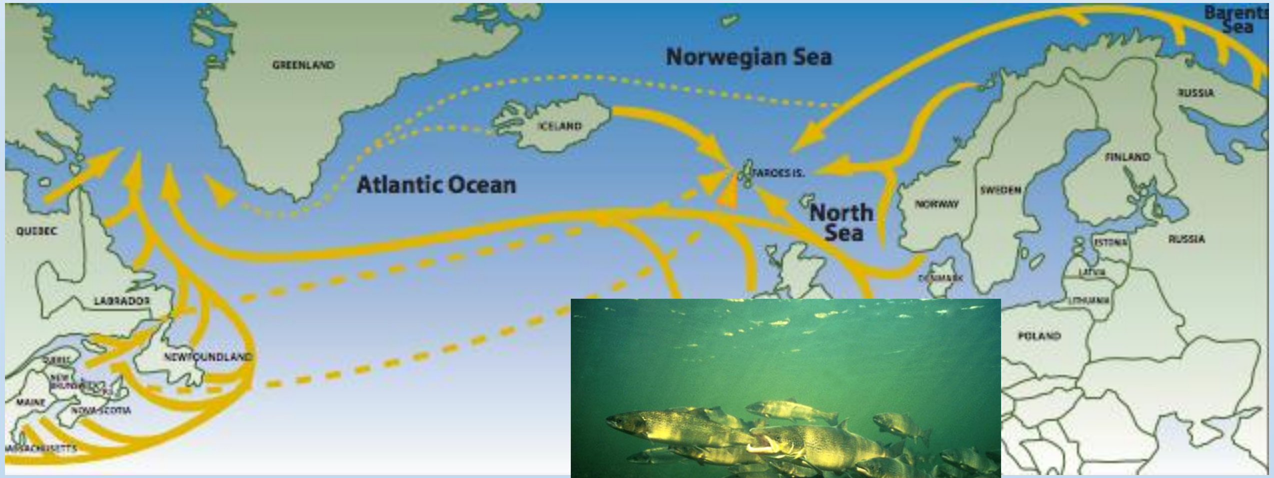


Photo: fishlarvae.org

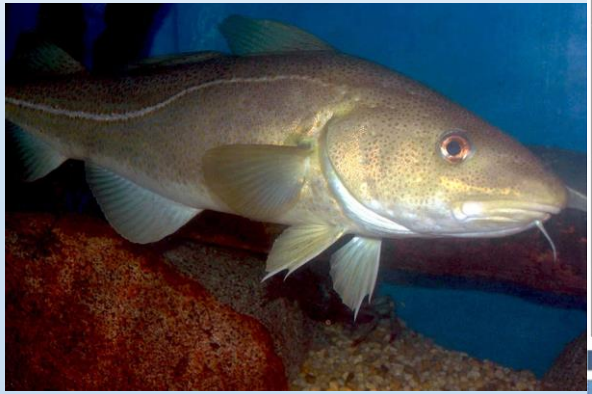


Photo: NOAA

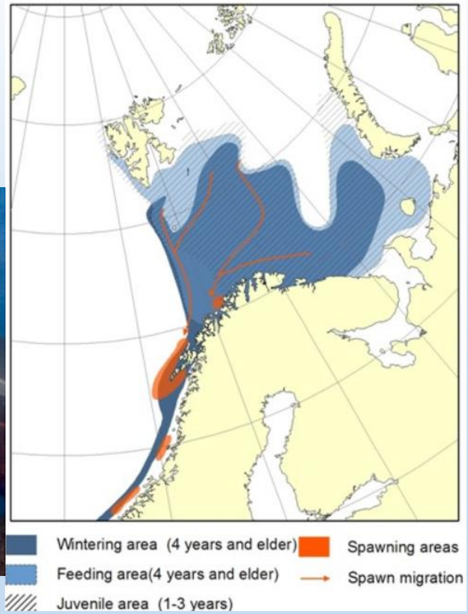
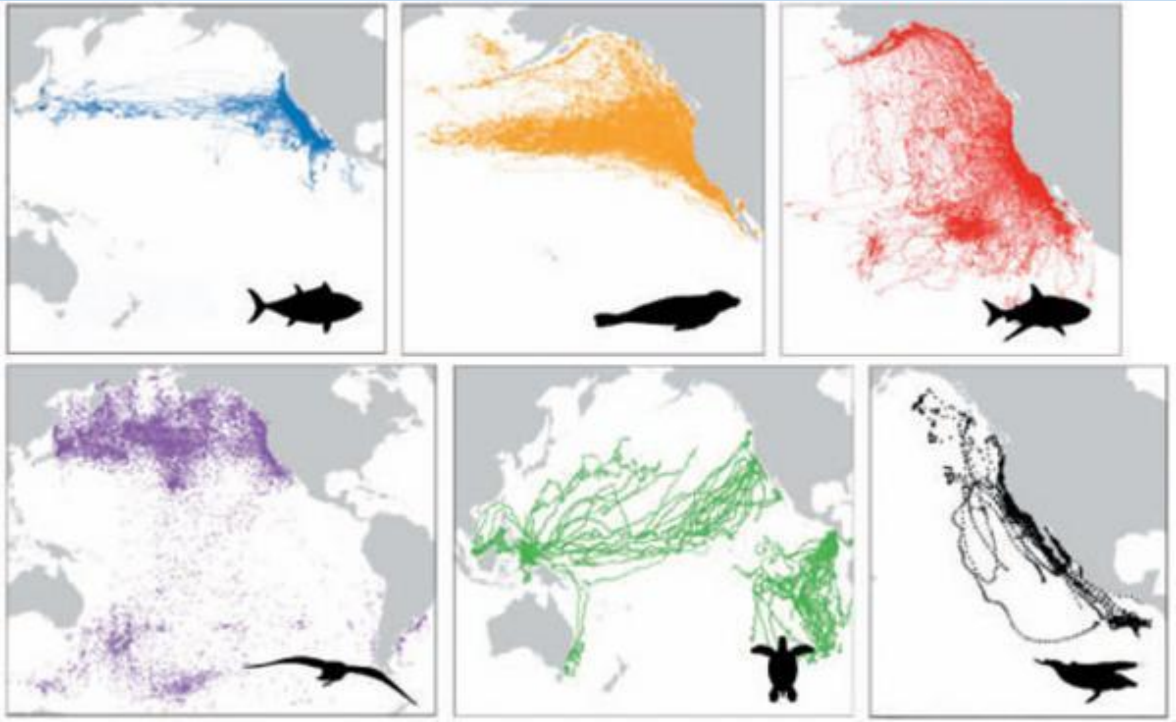


Photo: Jonny Armstrong / salmon-net.org

Beacham et al. 2014

Figure: Science



Block et al. 2011

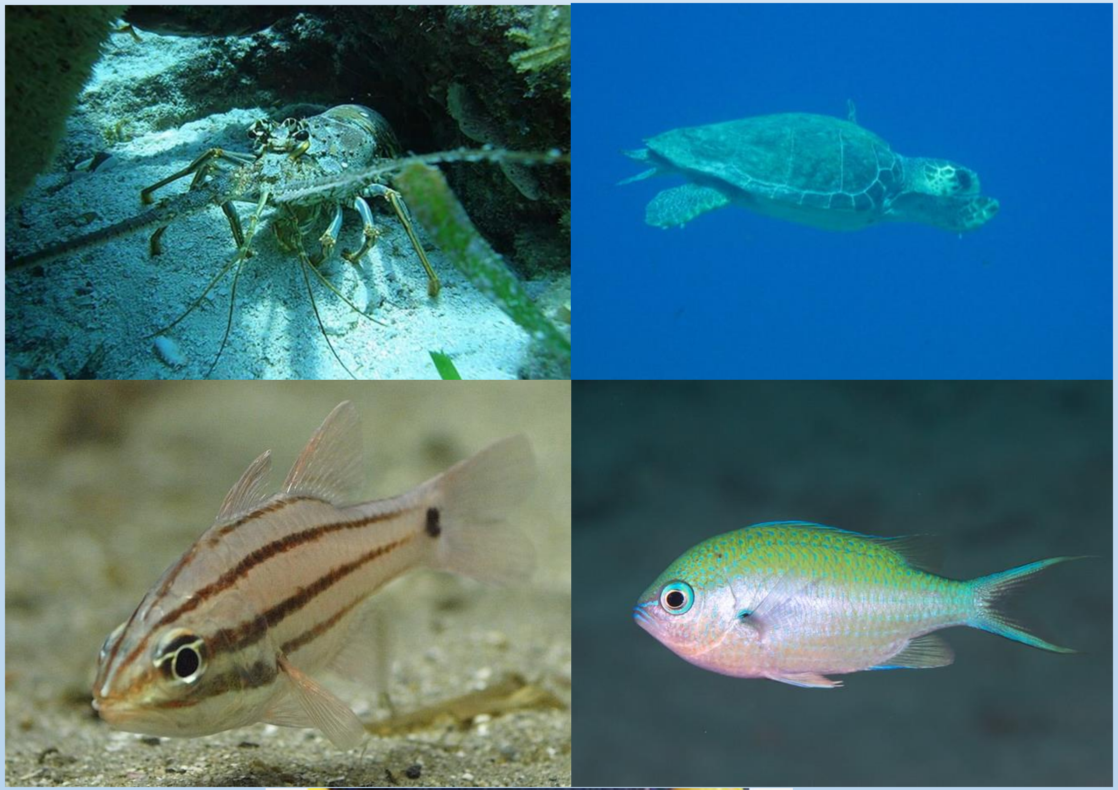
Long distance migration

- Orientation and movement preferences in European and Japanese **eels.** (Cresci et al. 2017, Durif et al. 2013, Nishi and Kawamura 2005, Nishi et al. 2004)
- Movement and route choice associated with magnetic field qualities in both **Pacific and Atlantic Salmon.** (Putman et al. 2013; ; Quinn 1980; Quinn and Groot 1983; Scanlan et al. 2018; Walker et al. 2003)
- **Tuna** discriminate shifts in magnetic field (Walker 1984)
- **Hammerhead shark** oriented in association with high intensity magnetic slope and can be conditioned to artificial magnetic fields (Klimley 1993)
- **Fin whale** migration correlate with areas of low geomagnetic intensity during migration, indicating the use of geomagnetic cues for navigation (Walker et al. 1992).

Photo: Jonny Armstrong / salmon-net.org, HI, fishlarvae.org, NOAA,

Local movement

- **Spiny lobsters** orient in the magnetic field, and likely also have a magnetic map sense to guide its local movements (Boles and Lohmann 2003, Lohmann et al. 1995)
- Juvenile **loggerhead turtle** use magnetic cues to orient away from shore, and to stay in feeding area currents (Goff et al. 1998, Lohmann et al. 2001, Lohmann and Lohmann 1996).
- **Antarctic amphipod** brought to a laboratory, moved in the geomagnetic seaward direction of their home beach (Tomanova and Vacha 2016).
- Larvae of **damselfish** and **cardinalfish** responded to shifts in magnetic field with corresponding shifts in orientation, demonstrating magnetic compass orientation and its potential use in homing or reef settlement (Bottesch et al. 2016, O'Connor and Muheim 2017).



Photos:
Pa - NPS
Cc - Nektarios Sylligardakis
Rickard Zerpe,
Ga - Maggie Amsler

Lack of knowledge

- Magnetite, a magnetic material used in magnetic orientation, has been found in a range of fish species, including herring, wolf-fish, mackerel, and dolphin *(Hanson and Westerberg 1987; Zoeger et al. 1981)*




Photos: Citron / CC-BY-SA-3.0; NOAA

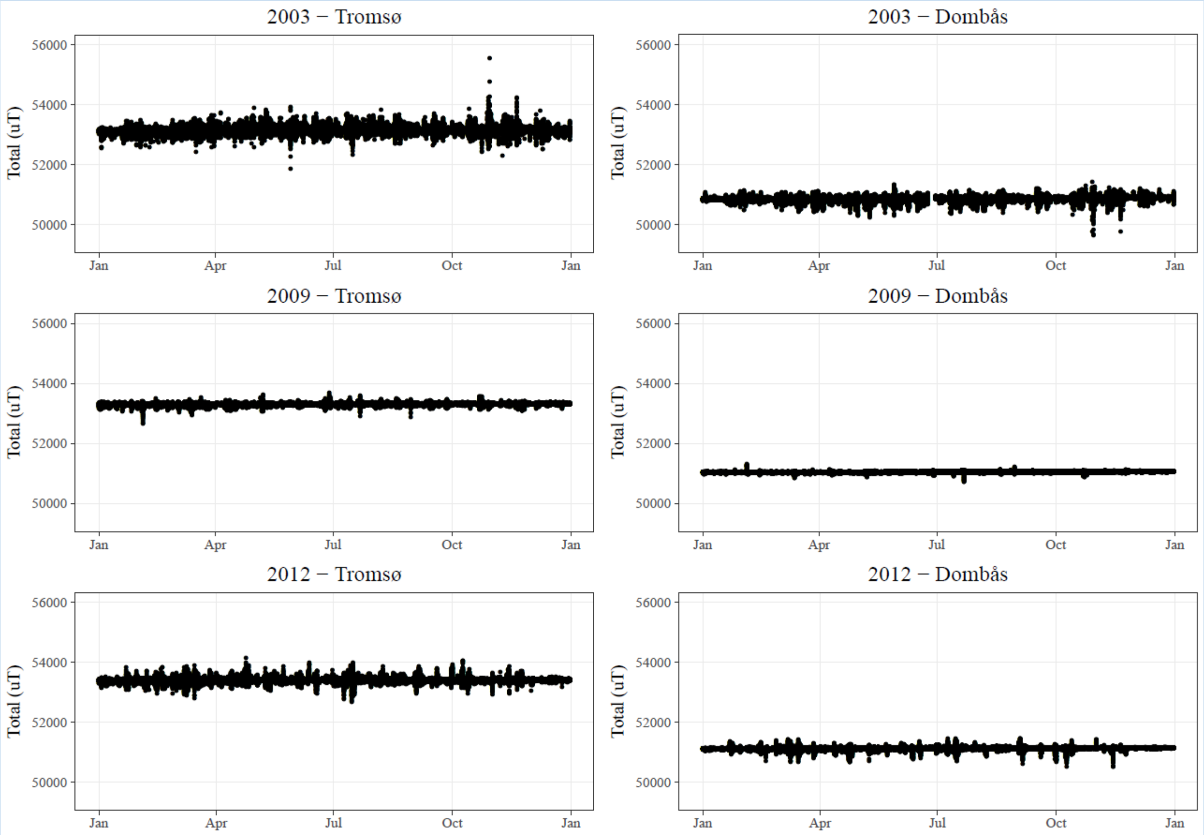
Effects of magnetic disturbances on animal behavior

NO PUBLISHED STUDIES ON EFFECTS OF ELECTROMAGNETIC SURVEYS ON ANIMAL BEHAVIOR?

Natural magnetic disturbances

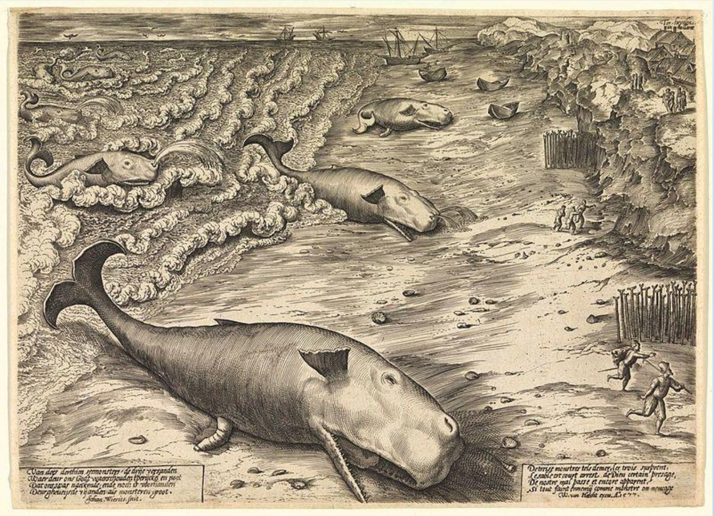
Solar radiation

- Local dirunal variation
  (few to over 500 nT)
- Minor disturbances
  (100 – 200 nT, last for minutes to days)
- Solar storms
  (sevaral 1000 nT, can last for days)



Natural magnetic disturbances

- Associations between live whale strandings and natural geomagnetic topography and disturbances have been observed. (Klinowska 1986; Kirschvink 1986).



- Herring supposedly migrated from shallow areas in the Barents Sea to deep waters of the Norwegian Sea during larger magnetic storms (Krylov et al. 2014).

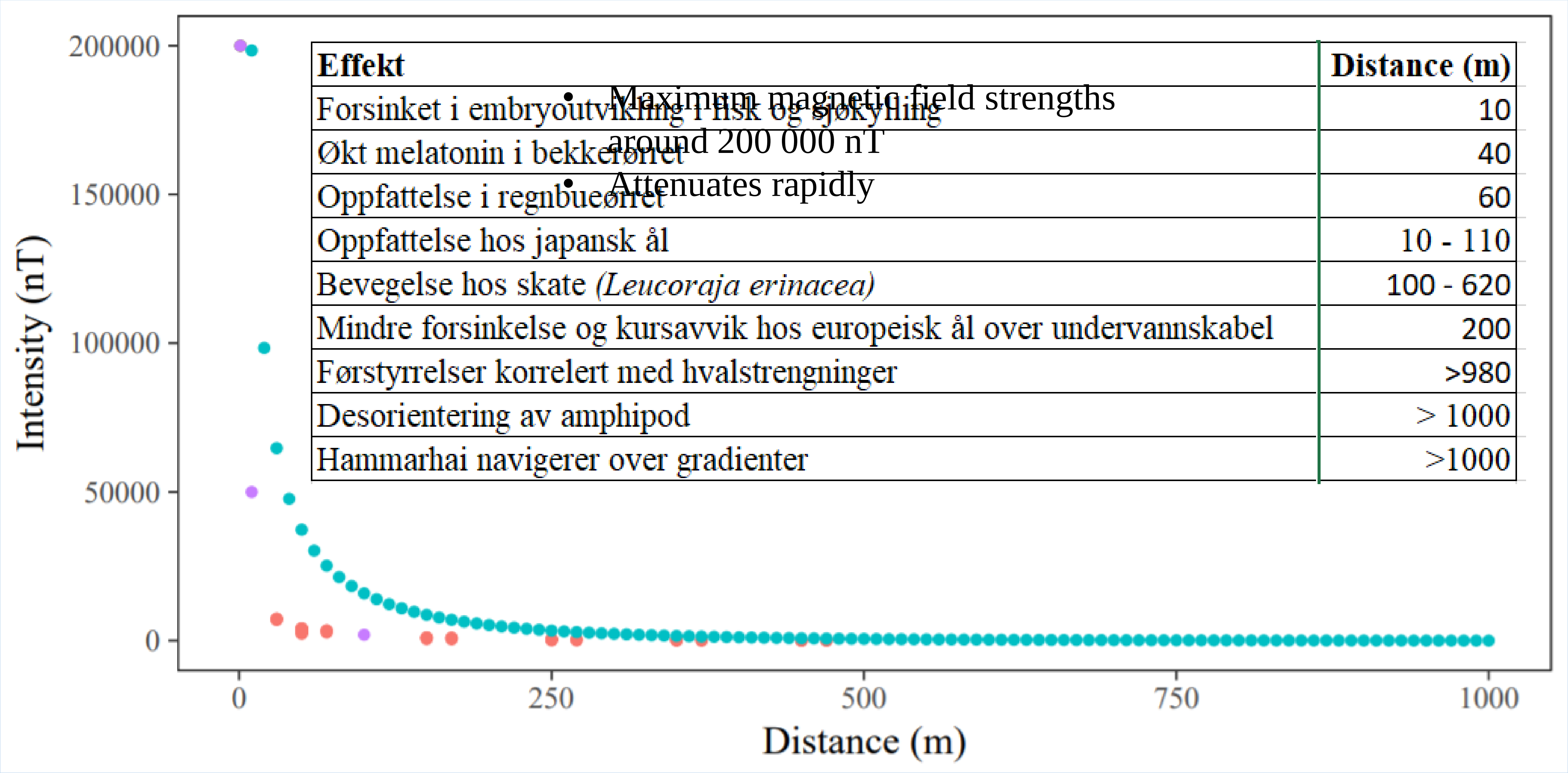
Electrical cables and magnets

- Under water electrical cables cause local deviation from the natural geomagnetic field.
  - European eels passing over an electric cable deviated their migration route, but resumed their migration direction after only a short average delay of 30 minutes (Westerberg and Begout-Anras 2000, Öhman et al. 2007).
  - Subtle movement and behavior effects in skates, lobsters, and crabs. (Scott et al. 2018; Hutchison et al. 2018)
- Strong magnets have been used, with mixed results, to reduce shark by-catch in baited fisheries (Hart and Collin 2015, Porsmoguer et al. 2015, Richards et al. 2018)



Photos: Andy Martinez/NOAA (Little skate); NOAA (American lobster); Crab - Christophe Quintin (edible crab)

Effects of magnetic disturbances on animal behavior



Effekt	Distance (m)
Forsinket i embryoutvikling i fisk og sjøkyling	10
Økt melatonin i bekkerørret	40
Oppfattelse i regnbueørret	60
Oppfattelse hos japansk ål	10 - 110
Bevegelse hos skate *(Leucoraja erinacea)*	100 - 620
Mindre forsinkelse og kursavvik hos europeisk ål over undervannskabel	200
Førstyrrelser korrelert med hvalstrengninger	>980
Desorientering av amphipod	> 1000
Hammarhai navigerer over gradienter	>1000

- Maximum magnetic field strengths around 200 000 nT
- Attenuates rapidly

Data from: Buchanan (2011), Johnsson & Oftedal (2011), EMGS (2018)

Referanse
Juutilainen 2005
Lerchl et al 1998
Hellinger and Hoffman 2009
Nishi et al 2004
Hutchison et al. 2018
Öhman et al 2007
Kirschvink 1986
Tomanova & Vacha 2016
Buchanan 2011

Electric fields and animals

- Some animals have also evolved to detect weak electric fields in their environment.
- Electroreception well demonstrated in elasmobranchs and chimeras
- Also present among lampreys, stargazers, sturgeons, catfishes and coelacanths

(Alves-Gomes 2001, Collin and Whitehead 2004, Walker 2001).

- Also reported response to relatively weak electric fields in Atlantic salmon and European eel (Rommel Jr and McCleave 1973)

Photos: Elias Levy, Andy Martinez/NOAA; Dan Hershman, NOAA, Buzz; Mauro Orlando; Daniel Jolivet

Electric fields in the sea

Electric fields are induced when saltwater moves in the natural magnetic field

→5 – 500 nV/cm in the English channel, North Sea, and Gulf stream *(Kalmijin 1999, Buchanan 2011)*

Photo: Maxipixel

Electric fields and animals

- All animals use electricity during their life-processes, for example in cell membrane transport, muscle contractions and nerve cell communication.
- Living organisms

  2000 – 100 000 nV/cm at very close range *(Heine et al. 2001*

Figure: Justin/Wikipedia

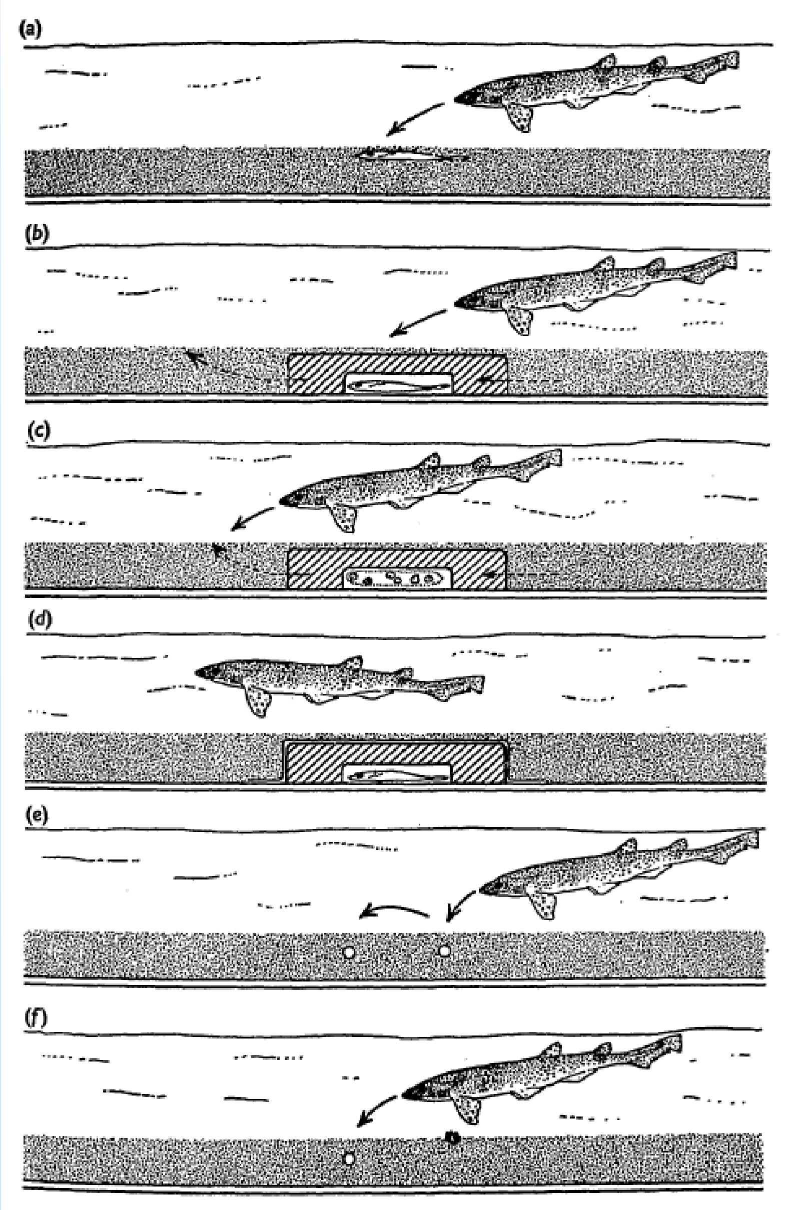
Electric sense

Electric cues, especially among elasmobranchs, have a much broader use than magnetic cues

- Prey detection (Kalmijin 1971)

Small-spotted catshark (Photo: joe)

Thornback skate



Electric sense

Electric cues, especially among elasmobranchs, have a much broader use than magnetic cues.

- Prey detection (Kalmijin 1971)
- Predator avoidance
  - skate and shark embryos ceased all ventilation when exposed to electric fields simulating ventilation pulses of a typical predator

Photo: Sander van der Wel

Electric sense

Electric cues, especially among elasmobranchs, have a much broader use than magnetic cues.

- Prey detection
- Predator avoidance
- Communication

    Stingray males can detect buried females using electric cues, and their sensitivity increases during the reproductive seaso.n

    (Bodznick et al. 2003, Sisneros et al. 1998, Sisneros and Tricas 2000)

Photo: Elias Levy

Electric sense

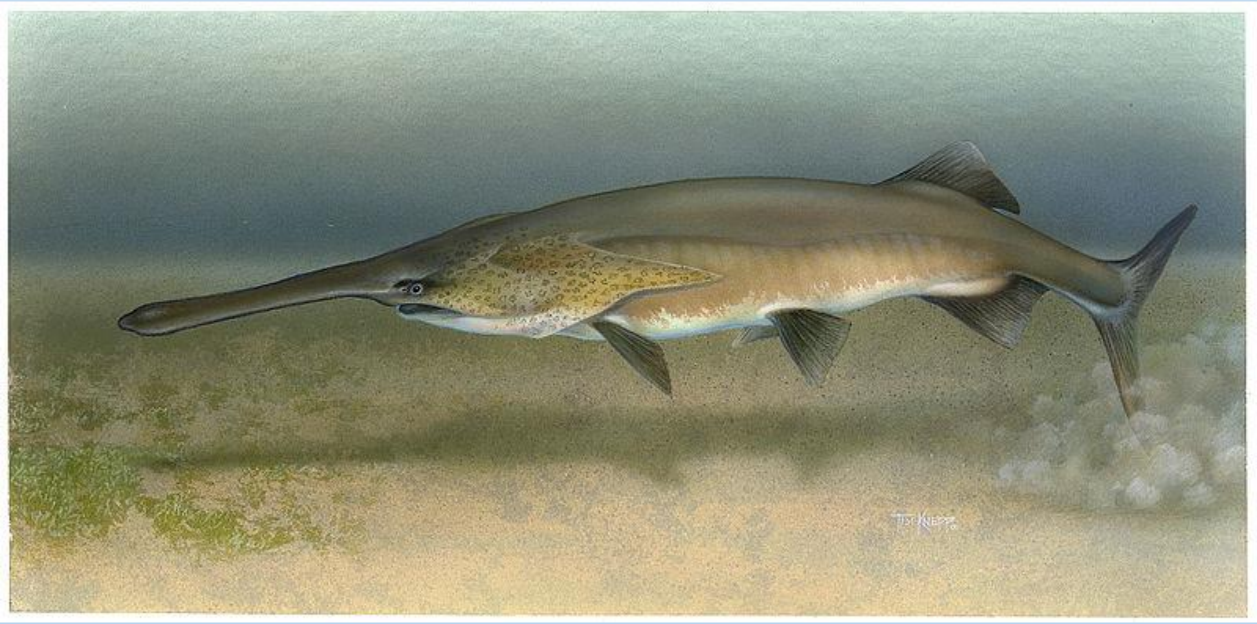
Electric cues, especially among elasmobranchs, have a much broader use than magnetic cues.

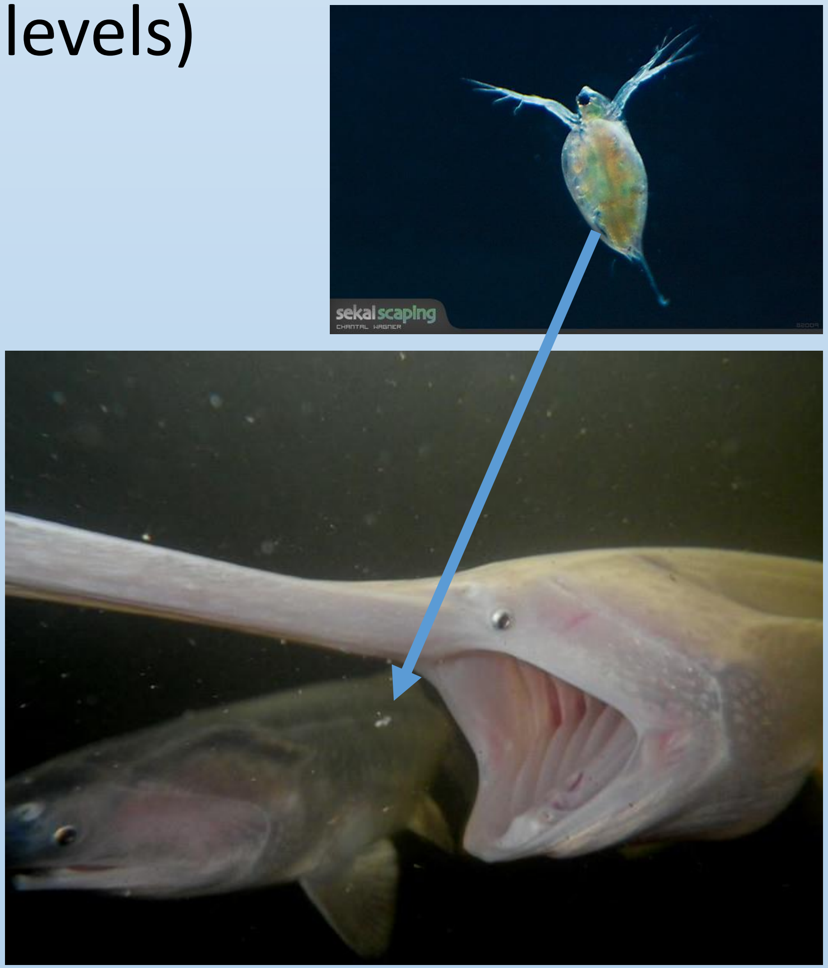
- Prey detection
- Predator avoidance
- Communication
- Geomagnetic orientation
  - Hammerhead shark oriented in association with high intensity magnetic slope and can be conditioned to artificial magnetic fields (Klimley 1993)

Photo: Kris-Mikael Krister

Anthropogenic electric fields and fish behavior

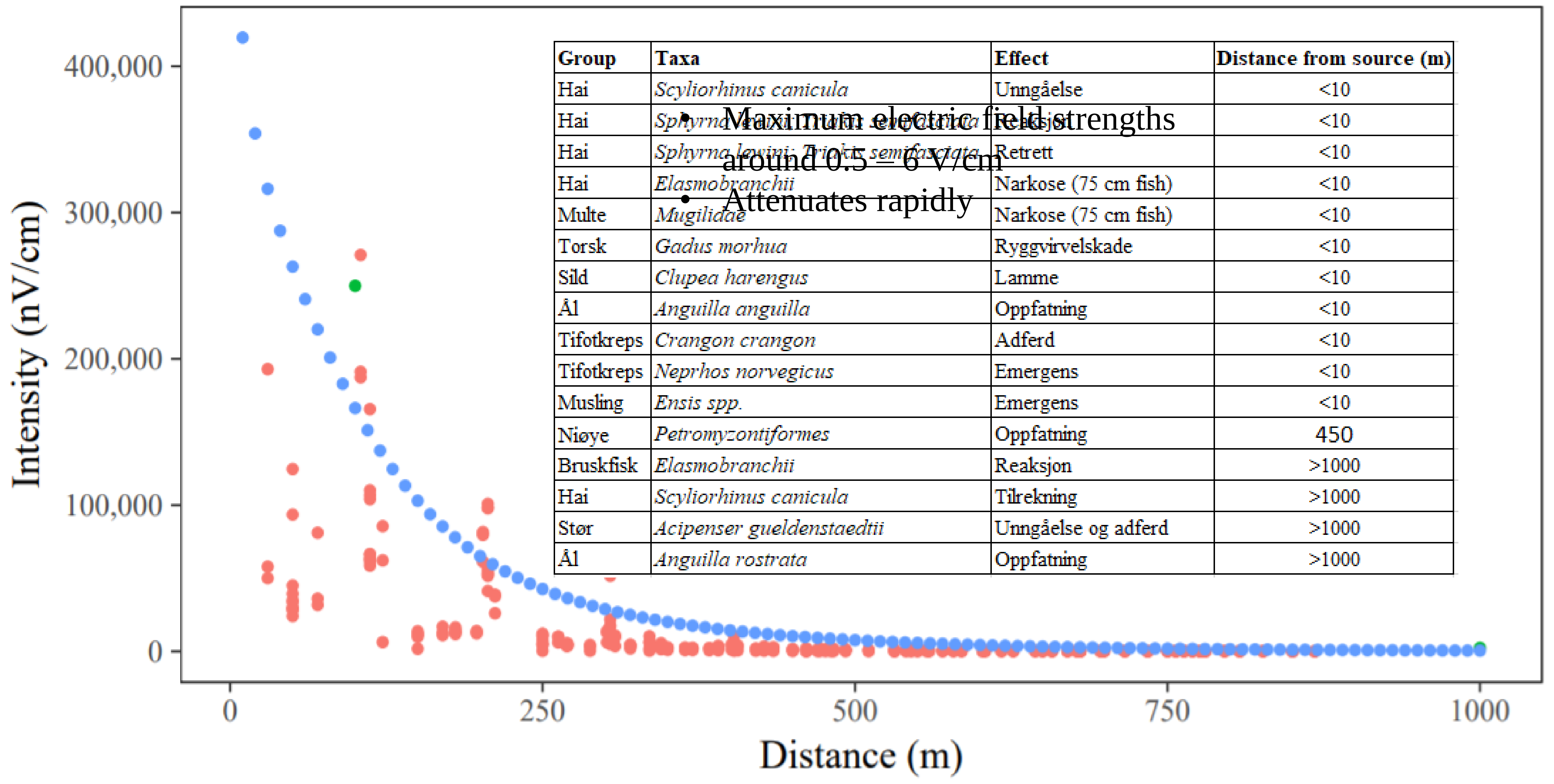
- Electrofishing and electronarcosis (high levels)
- Shark repellent (relatively high levels)
- Behvioral effects (low levels)





Images: USFWS & Chantal Wagner

Electromagnetic surveys



Group	Taxa	Effect	Distance from source (m)
Hai	*Scyliorhinus canicula*	Unngåelse	<10
Hai	*Sphyrna* [illegible] *semifasciata*	Reaksjon	<10
Hai	*Sphyrna lewini; Triakis semifasciata*	Retrett	<10
Hai	*Elasmobranchii*	Narkose (75 cm fish)	<10
Multe	*Mugilidae*	Narkose (75 cm fish)	<10
Torsk	*Gadus morhua*	Ryggvirvelskade	<10
Sild	*Clupea harengus*	Lamme	<10
Ål	*Anguilla anguilla*	Oppfatning	<10
Tifotkreps	*Crangon crangon*	Adferd	<10
Tifotkreps	*Neprhos norvegicus*	Emergens	<10
Musling	*Ensis spp.*	Emergens	<10
Niøye	*Petromyzontiformes*	Oppfatning	450
Bruskfisk	*Elasmobranchii*	Reaksjon	>1000
Hai	*Scyliorhinus canicula*	Tilrekning	>1000
Stør	*Acipenser gueldenstaedtii*	Unngåelse og adferd	>1000
Ål	*Anguilla rostrata*	Oppfatning	>1000

- Maximum electric field strengths around 0.5 – 6 V/cm
- Attenuates rapidly

Reference
Gill and Taylor 2001
Marcotte and Lowe 2008
Marcotte and Lowe 2008
Smith 1974 in Walker 2001
Smith 1974 in Walker 2001
De Haan et al 2011, cited in Soertaert et al 2015
Nordgren et al 2008
Unpublish, cited in Kullnick 2000
Polet et al. 2005
Stewart 1972, cited in Soetaert et al 2015
Woolmer et al 2011, cited in Soetaert et al 2015
Cited in Kullnick 2000
Peters et al. 2007
Gill and Taylor 2001
Basov 1999, cited in Fischer 2010
Rommel and McCleave 1972

Data from: Buchanan (2011), Johnsson & Oftedal (2011), EMGS (2018)

Conclusions

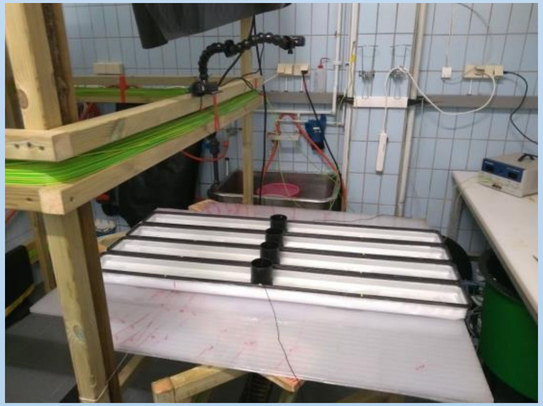
- No published studies on effects of electromagnetic surveys on animal behavior.
- A wide range of animals use magnetic and/or electric fields for orientation, communication, feeding, and predation avoidance
- Field intensities attenuate rapidly but should be perceivable by some animals at over 1 km distance.
- Effects are likely to be relatively localized in time and space, and concerning the behavior of the animals.

Potential effects?

- Long distance migratory behavior
  – eg. eel, salmon, herring.
- Localized movement
  - eg. lobster, settling larvae
- Escape responses
  - eg. elasmobranch reaction towards an increasing electric field.

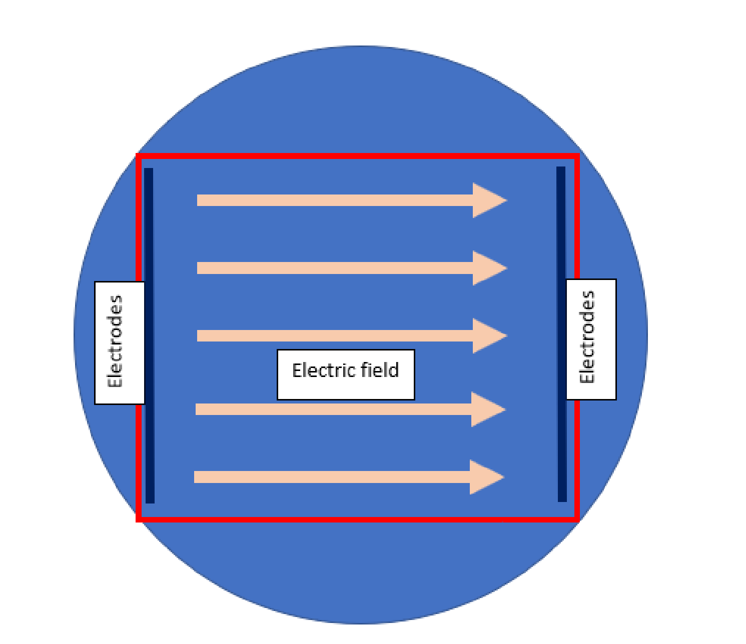
Future research?

- Magnetic sense in local species
  - eg. Sandeel, lumpfish



Future research?

- Behavioral effects of electromagnetic surveys – in tank and field
  - <u>Immediate effects</u> – startle responses, activity level, distribution.
  - <u>Effects on feeding behaviour</u> - feeding rate with and without the EM-fields.
  - <u>Effects on orientation</u>



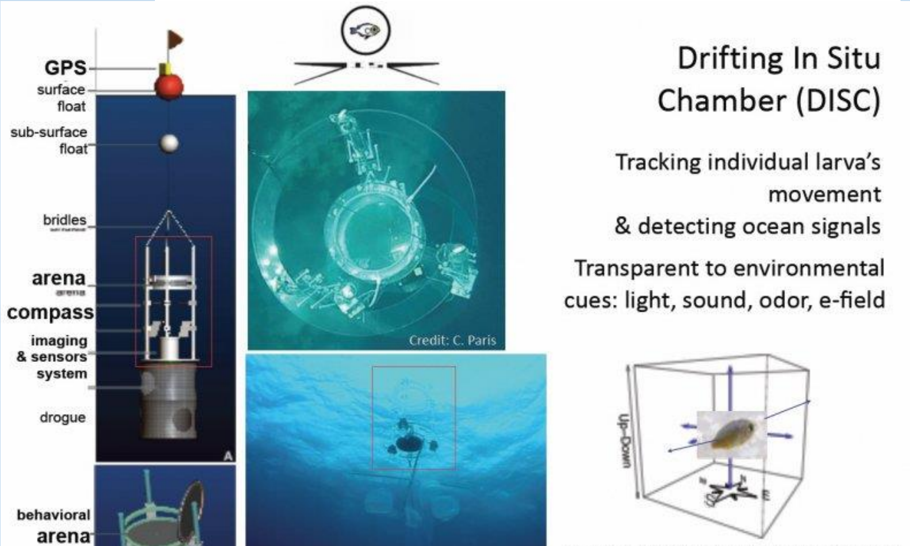


Figure 2. Drifting *In Situ* Chamber (DISC): view of the system (120 cm x 63 cm deployed at sea; the main underwater unit is composed of the behavioral arena (Ø 38 cm) and the imaging system in its housing

(Paris et al. 2008 *NMFS*, 2013 *PONE*)

Thank you for listening!

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