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Target strength and tilt angle distribution of lesser sandeel (*Ammodytes marinus*)

Master thesis of Ecology and Environmental Sciences

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Tobio (*Ammodytes marinus*) akustinio atspindžio ir vidutinio kūno polinkio kampo tyrimas

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SANTRAUKA

Rokas Kubilius

TOBIO (*AMMODYTES MARINUS*) AKUSTINIO ATSPINDŽIO IR VIDUTINIO KŪNO POLINKIO KAMPO TYRIMAS

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Darbo apimtis 55 puslapiai, 13 paveikslų ir 5 priedai (4 paveikslai, 7 lentelės).

ĮVADAS

Tobis (*Ammodytes marinus*) yra viena gausiausių Šiaurės jūros žuvų (Macer, 1966). Nenuostabu, kad ši žuvis yra svarbus mitybos šaltinis daugeliui aukščiau mitybos grandinėje esančių organizmų, kaip plėšriosios žuvys, kai kurie žinduoliai ir paukščiai (Furness ir Tasker, 2000; Frederiksen *ir kt.* 2004; ICES, 2006).

Šiaurės jūroje tobis yra patrauklus komercinės žūklės objektas. Ne vien tik dėl savo skaitlingumo, tačiau ir savybės formuoti didelius būrius, bei telktis sąlyginai nedideliuose, žvejų gerai žinomuose, jūros plotuose. Dvidešimto amžiaus antroje pusėje, pagal sugaunamos žuvies kiekius, tobis tapo svarbiausiu komercinės žūklės Šiaurės jūroje objektu, kurio sugavimai atskirais metais siekė milijoną tonų. Tačiau pastarąjį dešimtmetį sugavimai yra žymiai sumažėję (ICES, 2007). Panašu, kad tobio žūklės vadyba, grįsta vien komercinių sugavimų duomenimis, veikia prastai. Reikalingas šios žuvies gausumo vertinimas, kuris nesiremtų vien komerciniais sugavimais.

Žuvininkystės akustikos metodai yra sėkmingai taikomi kai kurių pelaginių žuvų gausumui vertinti (Gjøsæter *ir kt.*. 1998). Pažangūs akustiniai žuvų gausumo vertinimo metodai, vieni arba kombinuojami su kitais metadais, galėtų duoti tobio gausumo įvertį. Tuo remiantis šiuo metu yra vykdomas specialus mokslinių tyrimų Šiaurės jūroje projektas (Ona, 2007). Pakankamai tiksliam gausumo įvertinimui yra reikalinga turėti patikimus tobio akustinio atspindžio (TS) ir kūno polinkio kampo pasiskirstymo tokių eksperimentų metu duomenis, ypač kai žuvis yra pakankamai didelė duoti kryptingą atspindį su naudojamu echoloto dažniu.

Literatūroje galima rasti keletą aprašytų tobio akustinio atspindžio matavimo eksperimentų (Armstrong ir Edwards, 1985; Armstrong, 1986), tačiau rezultatai nėra pakankamai tikslūs, galbūt net abejotini dėl didelės rezultatų sklaidos apie vidurkį, kas skatina tyrimus tęsti. Tobio plaukimo pobūdis (kūno polinkio kampo pasiskirstymas) dar niekada anksčiau netirtas.

Šio darbo tikslas yra apskaičiuoti tobio (*Ammodytes marinus*) akustinio atspindžio stiprumą ir kūno polinkio kampą.

Uždaviniai šiam tikslui pasiekti yra:

- Rasti metodą, kaip išmatuoti tobio kūno polinkio kampą naudojant surinktus video duomenis;
- Ištirti tobio kūno polinkio kampo pasiskirstymą naudojant video duomenis surinktus lauko eksperimentų metu;
- Apskaičiuoti vidutinį tobio akustinį atspindį naudojant lauko eksperimentų metu surinktus duomenis.

LITERATŪROS APŽVALGA

Šiame skyriuje apžvelgiamos bendros žinios apie Šiaurės jūros tobį, jo ekologiją ir biologiją, žuvininkystės raidą. Apibendrinami pagrindiniai žuvų akustinio atspindžio tyrimo metodai, aptariant jų trūkumus, sunkumus ir privalumus, žuvų kūno polinkio kampo matavimų reikšmė ir metodai, ankstesni darbai, matuojant tobio akustinį atspindį. Skyrius yra išplėstas iki maksimalios pagal magistro darbo ruošimo reikalavimus leidžiamos apimties, siekiant suteikti kuo aiškesnį mokslo srities ir darbo tikslingumo supratimą skaitytojui, kuriam žuvininkystės akustika galbūt yra mažiau žinoma.

TYRIMO METODAI IR MEDŽIAGA

Darbo medžiaga buvo surinkta dviejų tobio monitoringo išvykų į Šiaurės jūrą metu (2007 ir 2008m, mokslinių tyrimų laivas “Johan Hjort“). Specialiai šiam tikslui padarytas kūbinis narvas buvo naudotas tris kartus 2007m ir vieną kartą 2008m. Du iš trijų 2007m eksperimentų buvo sėkmingi, kaskart surenkant apie 7-9val. akustinių ir 4-5val. video duomenų. Narvas su atvira apatine dalimi buvo nuleidžiamas ant dugno, kur sedimentuose slepiasi tobiai, gylis apie 40m. 2008m narvas buvo naudotas viena kartą. Narvas buvo visiškai uždaras, dengtas tinklu iš visų pusių, viduje anksčiau draga pagauti tobiai, experimento gylis apie 15-20m. Metalinio rėmo kubinis narvas (4 pav.) buvo aptrauktas smulkiaakiu tinklu, su įtaisytu 200kHz (ES-200-7CD išskaidyto spindulio siuntiklis-gaviklis) moksliniu echolotu viršuje ir video kamera (HDR-SR1E 2007m ir HDR-SR5E 2008m) narvo kampe bei aprūpintas baterijomis 48 valandoms autonominio darbo.

Akustinių duomenų peržiūrai ir apdorojimui naudotos dvi specialios kompiuterinės programos EK60 ir LSSS (Large Scale Survey System). Tobio akustinio atspindžio matavimai išrinkti rankiniu būdu naudojant dalį LSSS programinės įrangos paketo. Vėliau duomenys perkelti į Microsoft Excel programą tolesniam apdorojimui. Taip pat buvo išrinkti TS matavimai labai arti akustinės ašies (mažiau nei 1° nuo akustinės ašies), kur matavimai yra patys tiksliausi ir negali būti kritikuojami dėl atrimo nuo siuntiklio-daviklio atstumo efektų.

Video duomenų analizei panaudotos Vegas Pro 8.0 video analizės ir ImageJ nuotraukų analizės kompiuterinės programos. Video įrašo dalys, kur užfiksuoti tobiai, iškirptos nuotraukų pavidalu (15/sek.). Apie 1600 nuotraukų buvo atrinktos, kaip galimai tinkamos tobio kūno polinkio kampo analizei. Galiausiai, po detalios analizės su ImageJ, trečdalis jų buvo panaudotos tobio kūno polinkio kampo matavimams atlikti.

Matavimams su žemyn link jūros dugno nukreiptais akustiniais prietaisais yra svarbu žuvies kūno polinkis nuo horizontalės vertikaliame plane. Video kamera tiek 2007, tiek 2008m eksperimentuose buvo pakreipta žemyn (aukštyn), kas lėmė, jog tradiciniai tokiu duomenų analizės žuvies kūno polinkio kampo matavimams būdai netinka. Šiek tiek modifikuotas ir naujas būdas, tinkantis šiame darbe surinktų duomenų analizei, buvo sukurtas ir išvystytas autoriaus, aprašytas 2.4 poskyryje.

TYRIMO REZULTATAI IR JŲ APTARIMAS

Tobio vidutinis akustinis atspindys. Trijų eksperimentų akustiniai duomenys buvo išskaidyti į 5 duomenų grupes (patogumo dėlei pavadinti D2, D2L, D3, D3L ir 08D, žr. poskr. 3.2) ir kiekvienos jų analizė bei akustinio atspindžio vidurkis pateikti atskirai. 2007m abiejų eksperimentų akustiniai duomenys išskirti į dvi dalis. Abiem atvejais pačioje eksperimento pradžioje duomenų rankinio išrinkimo ir žuvų elgsenos, kas daro įtaką TS matavimams, sąlygos buvo šiek tiek kitokios nei tolimesnėje eksperimento eigoje. Tačiau analizei prieinamas tobio TS matavimų skaičius per didelis, kad ši surinktų duomenų dalis būtų ignoruojama ir nepanaudota. Eksperimentų duomenys nėra labai gausūs, tačiau bus naudingi kitų metų tobio monitoringo tyrimams, todėl buvo stengtasi išgauti kiek įmanoma daugiau rezultatų aptarimui. Tuo pačiu tikslu duomenys analizuoti ir palyginti dviejuose vandens sluoksniuose po akustiniu siuntkliu-gavikliu, kitapus vieno siuntiklio-gaviklio artimojo lauko atstumo, >0.55m (didesnis matavimų skaičius) ir kitapus dviejų, >1.1m (mažesnė matavimų paklaidos tikimybė). Akustinių duomenų analizės rezultatai pateikti 3.2 poskyryje ir 10 bei 11 paveiksluose.

D2 akustinių duomenų dalyje neabejotinai fiksuoti tobiai, tačiau būta ir objektų, kuriuos buvo sunku identifikuoti kaip tobius (dėl tikėtina per stipraus atspindžio bei neįprasto echogramoje fiksuoto plaukimo pobūdžio), tačiau buvo sunku ir atmesti. Galiausiai gautas vidutinis TS=61.0dB (10a pav.), kuris yra gerokai ir reikšmingai didesnis nei visų kitų matavimų (D2L, D3, D3L, 08D). Analizuojant kitas akustinių duomenų dalis ir lyginant su D2 buvo nuspręsta, kad kitos žuvies (ne tobio) buvimas narve yra tikėtinas, tačiau nebuvo įmanoma šių nepageidaujamų duomenų nufiltruoti kaip kad, pavyzdžiui, D3 duomenyse. Kaip aptarta 4 skyriuje, D2 vidurkinė TS reikšmė nebuvo panaudota skaičiuojant išvadose pateiktą tobio akustinio atspindžio ir kūno ilgio sąsajos lygtį. Iš kitų akustinių duomenų dalių išgauti TS vidurkiai yra tokie: D2L su -75.2dB, D3 su -70.2dB, D3L su -77.2dB ir 08D su -75.4dB. D3 duomenyse pastebėta kitos rūšies žuvis nei tobis (tikėtina kažkuri plekšnių rūšis), tačiau buvo lengva nereikalingus duomenis identifikuoti ir išmesti. Taip pat darbe aptariamas galimas planktono TS matavimų neteisingas priskyrimas tobiui ir galimas poveikis vidurkinių TS skaičiavimui. Kaip minėta buvo išrinkti ir TS matavimai labai arti akustinės ašies (mažiau nei 1° atstumu), čia akustinio atspindžio matavimai yra patys tiksliausi. Šie matavimai yra artimi kiekvienam iš penkių duomenų dalių TS vidurkių, nors ir statistiškai reikšmingai skiriasi visais penkiais atvejais. Tikėtina, kad skiriasi labiau dėl mažo matavimų skaičiaus taip arti akustinės ašies nei dėl akustinio spindulio formos galimų iškraipymų siuntiklio-daviklio priešakyje. Kita vertus surinkti duomenys to įrodyti negali.

Galiausiai apskaičiuoti vidurkiniai tobio TS pavaizduoti 13 pav., kur jie yra parodyti kaip akustinio atspindžio priklausomybė nuo žuvies kūno ilgio (logaritminėje skalėje), palyginant su visais kitais anksčiau atliktais tobio TS matavimais, taip pat išbrėžiant tobio TS priklausomybės nuo kūno ilgio logaritmo liniją, pagal priimtą tokios priklausomybės žuvims formulę $TS=20*\log_{10}(L) + b_{20}$. Iš šiame darbe prieinamų duomenų apskaičiuotas b_{20} tobiui yra 99.7, kas rodo, kad 20cm ilgio tobio TS turėtų būti –73.7dB.

Tobio kūno polinkio kampas. 3 skyriuje pateikiami rezultatai išanalizavus du video įrašus iš dviejų tobio narvo eksperimentų (2007m ir 2008m). Išanalizavus 2007 video įrašą (narvas ant dugno su viduje besileidžiančio narvo įkalintais tobiais) buvo gautos tokios vidutinės kūno polinkio kampo reikšmės: 1.4°, kaip įraše matytų žuvų vidurkis (vidurkis matavimų per žuvį, tada vidurkis visų žuvų) ir 1.8° (±3.1° su 95% pasitikėjimo intervalu, standartinė paklaida 24.1), kaip visų atskirų matavimų vidurkis (nuotrauka po nuotraukos). Išanalizavus 2008 metų tobio narvo video duomenis atitinkamai gautos 13.4° ir 23.3° (±3.0° su 95% pasitikėjimo intervalu, standartinė paklaida 25.4) tobio vidutinio kūno polinkio kampo reikšmės. Darbe aptartos kelios didelį skirtumą tarp dviejų eksperimentų matavimų galėjusios lemti priežastys, kaip besiskiriantis eksperimento dizainas, kas lėmė kitokias šviesos, narvo judesio bangose (2008) sąlygas, plaukimo elgsenos skirtumai. Štai 2007m eksperimento metu matytos žuvys kirsdavo kameros vaizdą kaip pavieniai individai su labai įvairuojančiu kūno polinkio kampu. Kita vertus 2008m eksperimente žuvys dažnai plauke po dvi ar daugiau, aiškiai koordinuodamos plaukimo kryptį tarpusavyje (žr. priedas nr.2. 1pav.). Tai primena žuvų elgseną būriuose, kurių formavimas būdingas ir tobiui. Kadangi tobiai jūroje dažniausiai aptinkami būriuose, tikėtina, kad ir vidutinio kūno polinkio reikšmė iš 2008m eksperimento yra artimesnė tikrajai.

IŠVADOS

1. Sukurtas metodas žuvies kūno polinkio kampui vertikalioje plokštumoje matuoti, kai duomenys surinkti naudojant kamerą, kurios nuotraukų plokštuma kitokia nei vertikali.
2. Apskaičiuotas tobio vidutinis kūno polinkio kampas yra 23.3° (standartinė paklaida 25.4). Surinkti duomenys gana riboti, todėl tyrimo rezultatai turėtų būti traktuojami kaip pirmasis mėginimas ištirti tobio vidutinį kūno polinkio kampą ir atskaitos taškas tolimesniam tyrimui.
3. Vidutinis tobio akustinio atspindžio stiprumas gali būti apskaičiuotas pagal akustinio atspindžio ir žuvies kūno ilgio priklausomybe: $TS=20*\log_{10}(L) - 99.7$. Gautas vidutinis tobio akustinis atspindys yra silpnas, palyginus su ankstesniais tyrimais. Todėl reikalingas šios žuvies akustinių savybių tolesnis tyrimas.

SUMMARY

Rokas Kubilius

TARGET STRENGTH AND TILT ANGLE DISTRIBUTION OF LESSER SANDEEL (*AMMODYTES MARINUS*)

Graduation thesis in master studies of Ecology and Environmental Sciences

Supervisor: PhD. Artūras Razinkovas
Consultant: Prof. Egil Ona

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Ecology department
Klaipėda, 2009

The coverage of the work is 55 pages, 13 pictures and 5 appendixes (4 pictures, 7 tables).

Lesser sandeel (*Ammodytes marinus*) was investigated acoustically as well as using video camera in two field experiments in 2007 and one in 2008, both during North Sea sandeel surveys by the Norwegian research vessel "Johan Hjort". Specially designed cubic cage was put on the sea bottom trapping sandeels inside in 2007, while in 2008 sandeels were caught by trawl and dredge and investigated acoustically in enclosed cage hanging in mid-water. In total 3 successful experiments conducted. Approximately 22 hours of acoustical and 11 hours of video data was available.

Lesser sandeel target strength measurements extracted using LSSS acoustical data post-processing software by manual handpicking. Pictures from video data grabbed with Vegas Pro 8.0 computer program and later carefully analyzed using ImageJ photo editing software. The way of calculating sandeel body tilt angle from data, collected with tilted camera, was developed by author.

In total 5 mean TS values were calculated and presented separately by discussing strengths and possible error sources in each of them. One of the calculated means was decided to be possibly erroneous and was not used for calculating target strength-length relationship equation. Resulted sandeel target strength-length relationship equation is $TS=20*\log_{10}(L) - 99.7$.

Sandeel tilt angle measurements from two experiment video data (2007 and 2008) differ from each other. 1.8° (±3.1° with 95% confidence interval) mean sandeel body tilt angle (as mean of all single tilt angle measurements) was calculated from 2007 video data and 23.3° (±3.0° with 95% conf.int.) from 2008 video data. Strong dispersion of single tilt angle measurements around the means was recorded (standard deviation of 24.1 and 25.4 for 2007 and 2008 data respectively).

INTRODUCTION

Lesser sandeel (*Ammodytes marinus*) is the most abundant sandeel species out of five found in the North Sea (Macer, 1966) and could be referred as one of the “key” species in the North Sea ecosystem. By being so abundant it is available to a range of predators, such as fishes, mammals and seabirds some of which have already shown to be highly dependent on this food source (Furness and Tasker, 2000; Frederiksen *et al.* 2004; ICES, 2006; Daunt *et al.* 2008).

Because of its aggregative and patchy distribution and often in high numbers lesser sandeel is an attractive object to commercial fishery. Sandeel became the largest single-species fishery in the North Sea with landings peak more than one million tonnes in late 1990’s and a significant decline afterwards (ICES, 2007). Current management of sandeel stocks is relying on Catch-Per-Unit-Effort (CPUE) based methods. On the other hand, with a declining stock amount and catches there is a demand for fishery independent data on sandeel abundance.

Sandeel stocks are difficult to survey by currently available abundance estimation methods. In order to address this issue a special project called “Survey Methods for Abundance Estimation of Sandeel (Ammodytes marinus) StoCks” (Ona, 2007) is being undertaken. Acoustic methods are well suited for abundance estimations of pelagic fish stocks (Gjøsæter *et al.* 1998), as well as for the description of the geographical distribution of the stock. Advanced acoustics in combination with other methods probably could deliver fishery independent data on sandeel stocks. From acoustical point of view, sandeel is quite a challenging object to survey, because it is a small and weak target. However, sandeel abundance estimation using acoustics has important advantages, like large sampling volume, high resolution in space and time and potentially lower cost as compared to trawl surveys. To achieve accurately scaled abundance estimates it is necessary to have reliable information on sandeels target strength (TS) and knowledge of the natural body tilt angle distribution during such measurements, especially for fish which is large enough to be directive scatterers at the operating echo sounder frequency. Although there were some experiments on sandeel target strength (Armstrong and Edwards, 1985; Armstrong, 1986), the resulting TS measurements were not precise enough, possibly doubtful due to very high variability, which called for further investigation. Lesser sandeel mean swimming orientation (tilt angle distribution) has yet not been examined.

The goal of this thesis is to estimate mean acoustic target strength and tilt angle distribution of lesser sandeel (*Ammodytes marinus*).

Objectives to reach this goal are:

- To develop a method for measuring the sandeel body tilt angle from the collected video data;
- To examine lesser sandeel tilt angle distribution using video data from field experiments;
- To estimate mean acoustic target strength of lesser sandeel using acoustic data from field experiments.

1. LITERATURE REVIEW

1.1 Biology and ecology of lesser sandeel (*Ammodytes marinus*)

Lesser sandeel (*Ammodytes marinus,* Raitt, 1934) is the most abundant sandeel species out of five found in the North Sea; the other species are *Ammodytes lancea* (Cuvier), *A. lanceolatus* (Lesauvage), *A. immaculatus* (Corbin) and *Gymnammodytes semisquamatus* (Jourdain) (Macer, 1966). Lesser sandeel is a small ell-like fish bearing no swim bladder and having relatively short life span. In catches sandeels usually appear up to 20-25cm in total length (Fig.1). Macer (1966) reported 9 years old lesser sandeel as oldest to be found, but industrial catches are usually dominated with I and II (III) year-class fishes. Majority of lesser sandeels spawn for the first time by being two years old, usually in December and January (North Sea). This fish feeds on plankton, according to Macer (1966), mostly on copepods, crustacean larvae and annelids. Lesser sandeel is schooling plankton feeder, usually swimming in big schools during the periods of activeness and burrowing into the bottom substrate for the night or wintering time. Lesser sandeel is widely distributed in coastal and shallow open North Sea waters (Macer, 1966).

Fig. 1. Lesser sandeel (*Ammodytes marinus*), caught using trawl during sandeel survey 2009 (RV "G.O. Sars"). Photo is taken by author.
1 pav. Tobis (Ammodytes marinus) pagautas tralu. Nuotrauka daryta 2009 metų tobio monitoringo išvykos metu (mokslinių tyrimų laivas „G.O. Sars“) šio darbo autoriaus.

Lesser sandeel (sandeel onwards) has an extremely patchy geographical distribution in the North Sea, due to the dependence on a specific sea bottom type (Wright *et al.* 2000). It appears that sandeel dislike fine sediments like silt. Wright's *et al.* (2000) experiments have shown a high importance of the fine particle fraction in bottom sediments on sandeels habitat selection and its distribution across the sea. As the sandeel do not make permanent burrow openings and for ventilation of gills they use water appearing inside bottom substrate, a high percentage of fine particles could block their gills.

By being one of the most abundant fish species in North Sea lesser sandeel is important prey for many predators, such as fishes, mammals and birds some of which have already shown a high dependence on this food source (Furness and Tasker, 2000; Frederiksen *et al.* 2004; ICES, 2006; Daunt *et al.* 2008). However, it is quite difficult to evaluate how large is the influence of sandeel fishery in the North Sea on its total ecosystem. For example, Frederiksen *et al.* (2004) showed quite clear relation between locally very sandeel-dependant and declining black-legged kittiwakes population size and sandeel fishery; on the other hand, Furness (2002) claimed that "…most seabirds and grey seals increased in numbers as the [sandeel] fishery grew and reached peak harvest" and "small-scale effects of sandeel fishing should not be overlooked". Nevertheless, locally, sandeel population can be very sensitive to intensive fishing, if sandeel's stationary life style after settlement is taken into account.

Sandeel has also become an important fish species for commercial fishery in the region. Commercial fishing on the North Sea sandeels, of which, by far the most abundant in catches is lesser sandeel, started in early 1950's (Macer, 1966). Landings in North Sea sandeel fishery were increasing towards approximately 500 thousand tonnes in 1983 and a peak of approximately at one million tonnes in 1988 and again in late 1990's. In the following years catches decreased with a drastic decline after year 2002 (ICES, 2007).

From 2003 onwards the condition of the North Sea (ICES area IV) sandeel stock is stated as drastically changed (ICES, 2007). The major change in landings from 2002 to 2003 mainly came from historically very low recruitment in year 2002. Now, a more robust stock assessment method is needed than the currently used conventional CPUE methods.

Advanced acoustic methods, in combination with fish capture devices, could potentially be used in a time and cost effective sandeel survey, giving fishery independent information on the stock. But there are still several problems to be solved before the method can be used in assessment (Ona, 2007). Acoustic methods can possibly identify substrate preferred by sandeel and therefore used in trawl and dredge surveys (Mackinson *et al.* 2004). On the other hand, standard acoustic methods for direct fish abundance estimations are also being tried (Ona, 2007; appendix 3).

1.2 Target strength (TS) measurements

When echosounder is transmitting acoustic energy into the water, objects with different density than water can be detected. Some of the transmitted energy is reflected back exactly in the opposite direction as a transmition and gives an echo for echosounder's receiver. "Target strength of the fish is a number which indicates the size of [such] echo." (Simmonds and Maclennan, 2005). For the beginning maybe easier to understand is related to target strength parameter σ_{bs} or backscattering cross section. Backscattering cross section is more meaningful parameter when it comes to physics. σ_{bs} is measured in square meters (m^2). As Simmonds and Maclennan (2005) writes it is described by intensity of the incident and backscattered sound waves. Let’s say I_i is an intensity of incident sound wave at the target distance and I_{bs} is the intensity of backscattered signal. I_{bs} will be dependant on distance R at which the backscattered signal intensity is measured. I_i is not dependant on R, because it is actual intensity at target distance. Then backscattering cross section can be expressed by formula:

$$\sigma_{bs} = \frac{R^2 \cdot I_{bs}}{I_i}. \tag{1}$$

Formula present above is quite simple approach to explain backscattering cross section and based on some assumptions. For more detail description of $б_{bs}$ see e.g. Simmonds and Maclennan, 2005.

Now target strength concept can be defined. Target strength (TS) is the backscattering cross section (б) expressed in decibels [dB]. TS is used because it is much easier to operate with. While most of the fish TS will be between some –60dB and -20dB, same values expressed in backscattering cross section will range from 0.000001 till 0.01m^2. Translation between TS and $б_{bs}$ can be made back and forward using such formula:

$$TS = 10\log_{10}(\sigma_{bs}). \tag{2}$$

Target strength (TS) of the fish is higher when the density difference between the fish body and the surrounding water is greater. In this way fishes that are bearing gas-filed swim bladder have much higher TS and are easier to detect than fishes without a swim bladder. Target strength is also size dependant as bigger fishes give a stronger echo than small fish. The relationship between the TS and the size of the fish has been determined for a range of important species. It is also important to notice that the fish orientation relative to the incoming sound wave is important for fishes larger than one wave length of the acoustic signal. The body tilt angle relative to the horizontal has thus great influence on the strength of the received echo. Most favourable tilt angles are close to the horizontal. TS decreases greatly with unfavourable tilt angles (see Fig.2).

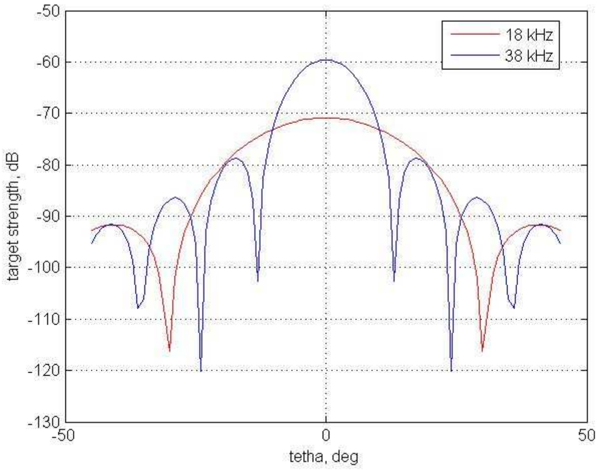


Fig.2. Theoretical computation of sandeel directivity pattern at two different frequencies is shown. Tetha is fish body tilt angle (produced by Gorska N. and Ona E., unpublished).
2 pav. Parodytas tobio akustinio atspindžio kryptingumas naudojant du skirtingus echoloto dažnius.

Quite a lot of information can be extracted from the received acoustic signal, for example its electrical properties, energy content, pulse duration, position, etc. However, the question is "…what do these measurements tell us about the insonified target?" (Simmonds and Maclennan, 2005). The goal of using acoustic instruments often is to get some quantitative information about insonified fishes, like in abundance estimation surveys. In order to do this it is necessary to know TS value which is representative for the fish acoustically surveyed. A range of different experimental TS measurement techniques were created.

1.2.1 Main TS measurement techniques

Most of TS measurement experiments and methods can be divided into three groups according to the investigated state of fish: immobile, unconscious fish; caged, but alive and active fish; wild fish, free to behave as in its natural habitat (Simmonds and Maclennan, 2005). First two methods are *ex situ* and the last one is *in situ*, with regard to whether or not the investigated fish appears in natural environment. A very brief description of these methods will be given, alongside with their main advantages and limitations. A deeper insight to *in situ* TS measurements will follow in the section (1.2.2) bellow.

For TS measurements it is necessary to not only use a calibrated echosounder, but also to have a good knowledge of species, their quantity and size distribution as well. The early target strength experiments were *ex situ* and mostly done on dead/immobile fish (Midttun and Hoff, 1965; Haslett, 1970; Nakken and Olsen, 1977). Fishes used in such experiments are wired with thin, acoustically almost invisible nylon lines. The object position in water could be changed by adjusting lengths of wires; allowing for TS measurements at any insonification angle. These experiments did not represent natural body positions and tilts. However, the method gives a very detailed insight into acoustical properties of the fish body. Nevertheless, the experiment conditions are very different from natural and "…target strengths measured in such experiments are now considered too inaccurate to be used directly for the interpretation of survey results" (Simmonds and Maclennan, 2005). The target strengths which are obtained using live fish in cages provide with more reliable TS for practical usage.

As mentioned before, target strength is dependant on the tilt angle of the insonified fish and, in fact, the variation with angle is quite large. For this reason, the experiment with live and actively swimming fishes is more likely to give suitable TS for acoustic surveys in the sea, as they represents measurements over a large range of orientation angles. TS experiments with caged fish can be done using one fish, aggregations or schools of fish. Usually the fishes are caught in other places of the sea and brought to the experimental site, then caged and submerged to some depth. Cage is often equipped with video camera observing fish behaviour or for tilt angle examinations. Cage-measurement methods for TS with a group of free-swimming fishes in the cage was first proposed in late 1970's, later developed and used in a series of TS experiments by Edwards and Armstrong (Simmonds and Maclennan, 2005). Some of these experiments also were the first attempts to estimate target strength of lesser sandeel (Armstrong and Edwards, 1985; Armstrong, 1986). By conducting experiments with caged fish it is easy to get biological data on acoustically examined objects (species, size, other if needed), knowledge on TS variation with time and depth, and also to examine small and/or weak acoustic targets. On the other hand, target strength measurements on caged fish are still *ex situ* method as the fish is caught, brought to the experimental site and then put into the cage. This approach may give result which can be questioned with respect to if the fish have behaved like under "normal" field conditions. Due to this, TS measurements obtained with the cage method in acoustical surveys should be used with caution and with full insight to understanding of its limitations.

Target strength experiments with immobile and caged fishes gave a good insight into various acoustical properties of the fish. The showed dependences on environmental and physiological factors, yielded target strengths often are hard to use in practice and rely on when surveying fish stocks in the sea and analysing collected acoustical data (Simmonds and Maclennan, 2005). More reliable are TS that are measured *in situ*, but this is also the most difficult way of measuring target strength of a fish.

1.2.2 *In situ* target strength measurements

It should be stated that experiments when using caged (or immobilized) fish may provide a better understanding on target strength's nature. However, capturing, transporting and caging the fish will probably have some influence on the target strength. TS yielded form caged/immobilized fishes can therefore be different than target strength of wild fishes. A good example, to illustrate this statement, could be for naturally schooling fishes, which when confined inside a cage may not school in the same way as in nature. Their important orientation pattern, or tilt angle distribution may be different. It would be better to make target strength measurement on wild fish in its natural habitat, without any disturbance or influence on its behaviour. "This type of measurements are said to be performed *in situ*, which means that target strength is determined while the fishes remain in place and, all being well, unaware of what is going on" (Simmonds and Maclennan, 2005). There are few methods for *in situ* target strength measurements, such as so-called comparison method, direct and indirect target strength measurement methods.

Comparison method for TS measurements

Knowing target strength and acoustical measurements from echo-integrator it is possible to calculate fish density. Contrary, if the fish density is known, TS can be extracted from echo integrator data. Simmonds and Maclennan (2005) call this method as a comparison method. To make such TS measurements it is necessary to obtain fish density information independently form acoustical data. As an example, a work done by Misund and Beltestad (1996) could be mentioned. They used the comparison method to estimate TS of schooling herring and mackerel. Firstly, schools of fish were crossed a few times to get echo-integrator data and subsequently caught by purse seiner. Therefore, the area and vertical extent of fish schools was measured at the same time. Finally, the density measure was calculated, when the entire school of fish was caught and catch size was divided by a volume of the school. Then mean TS can be estimated. One point should be noticed, to run this type of TS experiment it is necessary to have a well-defined fish school that is easy enough to catch. In the work, conducted by Misund and Beltestad (1996), only a small part of acoustically examined mackerel schools were caught entirely, with better results only on herring (5 of 8 schools caught entirely).

Another way to use this method is to use a trawl (or other fishing gear) to sample depth layer that was examined acoustically. Then catch rate by fishing gear can be used for fish density estimation and the echo-integration data for getting mean target strength. As Simmonds and Maclennan (2005) noted, such technique has been used for TS investigation of demersal fish and euphausiids, but also an important and potentially dangerous for bias assumption of catching all the animals within the swept water volume has to be made.

Direct and indirect TS measurements

Other two *in situ* target strength measurement methods are the so-called direct and indirect TS measurements. Direct and indirect target strength measurements are used to measure TS of individual fishes. Direct TS measurement can be performed with split-beam or dual-beam echosounders. It is possible to measure not only echo energy, but to extract information on fish position in the acoustic beam as well. When the target position within the beam is known, it is not difficult to compensate for the effects of transducer directivity pattern. Single-beam echosounder can also be used, but then it is necessary to make the assumption that measured targets are randomly distributed across the beam. These TS measurements are therefore defined as being obtained indirectly. Here the target strength can be estimated from recorded echo-energy distribution, when the beam pattern is known.

It is important to show and discuss a few important problems associated with *in situ* TS measurements on individual fishes (see Simmonds and Maclennan, 2005). These are: problems with single-target detection; are the targets detected and measured targets representative to insonified ensemble of the fishes or not, and further problems associated with representative sampling by the fishing gear used for obtaining biological data (length, species).

It is some problems related to single target detection that has to be accounted for. Received signal after the transmition of a ping is composed from a series of echoes. Each echo comes form one or several targets in the water column. The question is how close they are to each other (within the same acoustic sampling volume or not). For TS measurements it is crucial to filter out echoes that come from more than one fish. Echoes form such fishes is overlapping into one echo and will probably yield higher TS than it should be, if used for target strength measurements. This filtering is done automatically by echosounder based on properties of the received signal or "echo", like duration, amplitude stability or other (Ona and Barange, 1999). However, currently used automatic filtering methods for single-targets are imperfect and some multiple targets can be accepted as single ones (Simmonds and Maclennan, 2005; Soule *et al.* 1995). This problem can be small for large targets in low density (e.g. cod), but possibly severe in schools of small fishes (Simmonds and Maclennan, 2005). In other words, quality of single-target detection algorithm and density of the fish is important.

Other problem related with *in situ* TS measurements is whether or not the target, whose echo passes single-target detection filter, is representative. This question could arise when measuring TS on fish that tends to form dense schools. Single-target detector discard overlapping echoes from multiple-targets, this means that TS measurements are more likely to be made on fish occurring outside the main aggregation. Obtained TS may not be representative for schooling fish, as the measured fishes may not show typical school behaviour, e.g. have different tilt angles.

An important part of *in situ* target strength measurement is to get a representative sample of acoustically observed fish (for length and species identification). Only after relating TS measurements with specific targets it is possible to validate it. Often it is done by fishing with trawl or purse seiner. It is not a perfect sampling gear, because acoustically examined fish is not necessarily caught, gears are not equally good on catching all sizes of fish, etc. In case of trawl, it is often used after acoustic sampling, meaning that acoustic transect is repeated hoping to catch representative part of the same fishes. On other hand, if acoustically examined fishes form a large and uniform fish aggregation, representative sampling by trawl could be easy enough (Simmonds and Maclennan, 2005).

To measure target strength using *in situ* methods means to meet a lot of practical problems. Nevertheless, measurements on wild fishes in their natural environment are the most reliable, when it comes to the problem of estimating fish abundance from acoustic data collected on surveys.

1.3 Earlier work on lesser sandeel target strength

On some earlier surveys it was attempted to identify sandeel by using a combination of two frequencies, 38 and 120 kHz (Hassel *et al.* 2004; Mackinson *et al.* 2005). Some expected problems also were met. Mackinson *et al.* (2005) were already trying to estimate sandeel biomass acoustically (to the extent needed for the goal of their work). Some problems were reported, namely large uncertainty and lack of knowledge on sandeel TS as well as sandeels limited availability for acoustic instruments. In recent years multi-frequency acoustics combining 18, 38, 120 and 200 kHz frequencies have been quite successfully attempted for the identification and isolation of sandeel from mackerel and herring schools (Zahor, 2006). For acoustic abundance measurements, it is necessary to know target strength of this fish at one, maybe at several frequencies. It is also preferable to define the uncertainty of TS estimation.

Sandeel acoustic properties have been investigated before (Armstrong and Edwards, 1985; Armstrong, 1986). It was done using 38 and 120 kHz frequencies with caged and ensembled fish. The acoustic data from high numbers of fishes was collected over several days. Finally mean TS per individual was estimated by dividing mean backscattered acoustic energy by the number of individuals that were kept in the cage. Authors also mentioned an attempt to investigate sandeel tilt angle distribution by using video camera near the cage, however due to a very high fish density it was impossible. These two studies reported fairly weak and variable mean TS of individual sandeel, ranging from -68,6dB till -77,9dB at 38 kHz. As one of the possible explanations for this large range in estimated mean target strength, sandeel's burrowing behaviour during the night time was mentioned. Armstrong and Edwards (1985) also noticed that sandeel target strength at 120 kHz is at least 4dB higher than at 38 kHz, but this is not supported by Zahor (2006), who investigated sandeel schools by using multi frequency acoustics. Recently Johnsen *et al.* (2009) used multi frequency acoustics by investigating sandeel schools. This study shows that sandeel aggregations can be successfully identified and two most abundant age groups (I and II) can be distinguished acoustically.

A work by Thomas *et al.* (2002) on Pacific sand lance (*Ammodytes hexapterus*) should be mentioned as well. The investigation was TS measurements on caged single fishes using 120 kHz sounder. Pacific sand lance is a fish from the same genus like lesser sandeel. Measured sand lance target strength was compared and expected to be similar to lesser sandeel's TS in works by Armstrong and Edwards (1985) and Armstrong (1986). It appeared to be significantly higher. The difference between these results remains unclear. Possible explanations are difference in experimental approach and frequency of measurements as was discussed by authors.

In conclusion, the knowledge on lesser sandeel target strength is still incomplete. Currently the available data comes from *ex situ* experiments, where conditions are quite different from natural, giving some doubts on reliability of the results. In addition, some of the results are presented as a wide range in TS that gives little use in practice on sandeel surveys.

1.4 Fish body tilt angle measurements

Fish vertical orientation is one of the most important factors that create the variation in strength of echo from single fish targets (Foote, 1980; Hazen and Horne, 2004; Henderson *et al.* 2007). Video and photo cameras have been used for decades to measure tilt angles of insonified fish (Foote and Ona, 1987; Kang *et al.* 2005). A much used method is to mount a camera on or near a cage, with captured fish. Alternatively, a camera can also be lowered from a boat into schools of fish as done by Foote and Ona (1987). For both cage and *in situ* experiments, the echosounder is usually facing downwards to measure the TS. Hence to observe the vertical orientation of the fish camera is facing directly to a side. If possible, a line with a weight can be put in front of the camera for better vertical reference in pictures. Although, it is easer to take picture of caged fish, there is a possibility that caught, transported and caged fish have a different swimming behaviour than wild one. Especially, it could be difficult to handle schooling fishes. It is unlikely that schooling behaviour and tilt angles in captivity are the same in a cage as in natural environment. On the other hand, the caged fish is usually close to the camera, which enhances the quality of the photos. More natural conditions are present during in situ experiments. However, it may be difficult to find suitable schools, not all fishes are schooling and a school may disappear before the camera is in position to shoot pictures. Rough sea and water currents also can be critical for *in situ* experiments. Even in calm sea it is difficult to be sure that the camera is in a vertical position.

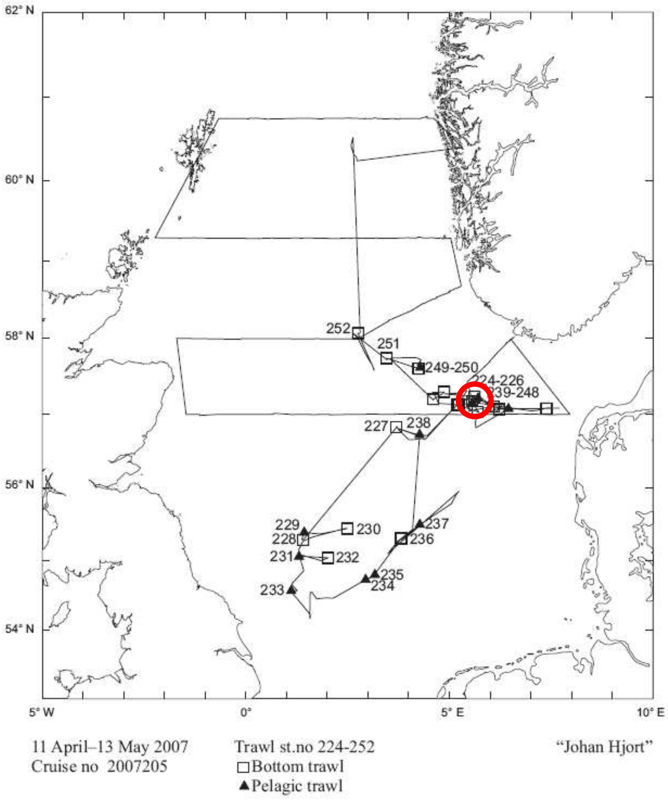
More advanced way to measure the tilt angle of a fish is the target tracking by using split-beam echosounder (Huse and Ona, 1996; Ona, 2001; McQuinn and Winger, 2003; Henderson *et al.* 2007). It is possible to track the target when it moves across the beam, and by examining swimming orientation the body tilt angle can be estimated. This method does not disturb the fish, in its natural environment, but representative sampling and species identification is a challenge. The usage of this *in situ* method on weak targets, small fish (e.g. sandeel) and at relatively big depths is impossible. One more potential constraint is that the fish do not necessarily have the same body tilt angle as its swimming direction angle, especially with low swimming speed.

All the methods to examine the tilt angle of fish have constraints which have to be considered when analysing the data. However, as the strength of the fish acoustic backscattering is strongly influenced by the tilt angle distribution, more knowledge is needed. Sandeel body orientation have never been examined before, neither using video/photo cameras nor acoustic target tracking.

2. MATERIALS AND METHODS

2.1 Study area

Acoustic and video data used in this thesis were collected during two sandeel surveys conducted by research vessel "Johan Hjort" in the North Sea in April-May 2007 and 2008 (visiting the same sea areas that are preferred by sandeel). A sandeel cage was dropped on the sea bottom 3 times in 2007 (04.23; 04.25 and 04.26), for periods of 7-9 hours (experiment sites, exact position and timing is presented in Fig.3). First of three experiments failed (07.04.23).



Deployment No.	Position		Time	Duration in hours
	Lat	Long	Setting / Hauling	
1	57° 11'	005° 34'	23.00 / 08.00	9
2	57° 10'	005° 33'	02.00 / 11.00	9
3	57° 10'	005° 33'	02.00 / 09.00	7

Fig.3. Left: map of survey conducted by RV "Johan Hjort" in 2007, main part of which was dedicated for sandeel. Red circle marks sandeel cage deployment sites, numbers show bottom and pelagic trawl stations for sandeel (modified after Survey report, 2007); right: table with exact positions and time of sandeel cage deployments.

3 pav. Dešinėje: transektos, nuplauktos mokslinių tyrimų laivu „Johan Hjort“ 2007m žemėlapis, kai buvo renkami duomenys apie Šiaurės jūros tobį. Raudonas apskritimas žymi „tobio narvo“ eksperimentų vietą; dešinėje: lentelė su informacija apie eksperimentų vietą, paros laiką bei bendrą eksperimento trukmę.

In 2008, the cage was used only once (2008.05.08). sandeels caught by trawl and dredge were investigated acoustically in enclosed cage hanging in mid-water (open sea, approximately same place like in 2007). Video camera was mounted and running.

2.2 Cage design

A cubic metal-frame cage was designed for the experiments and used in the 2007 and 2008 sandeel surveys (Fig.4). The cage frame was made using 30mm steel pipes. Length, height and width of the cage was 2,8 meter. Cage frame was covered with 5mm nylon sandeel net on five sides (2007 sandeel-cage experiment). To fully trap sandeel in the cage after lowering it on the sea bottom 10cm wide flat iron peaces were fixed on lower metal frame for proper penetration into sediments and enclosure of the cage. The steel ropes were attached to the cage for lowering it on the sea bottom (Fig.4).

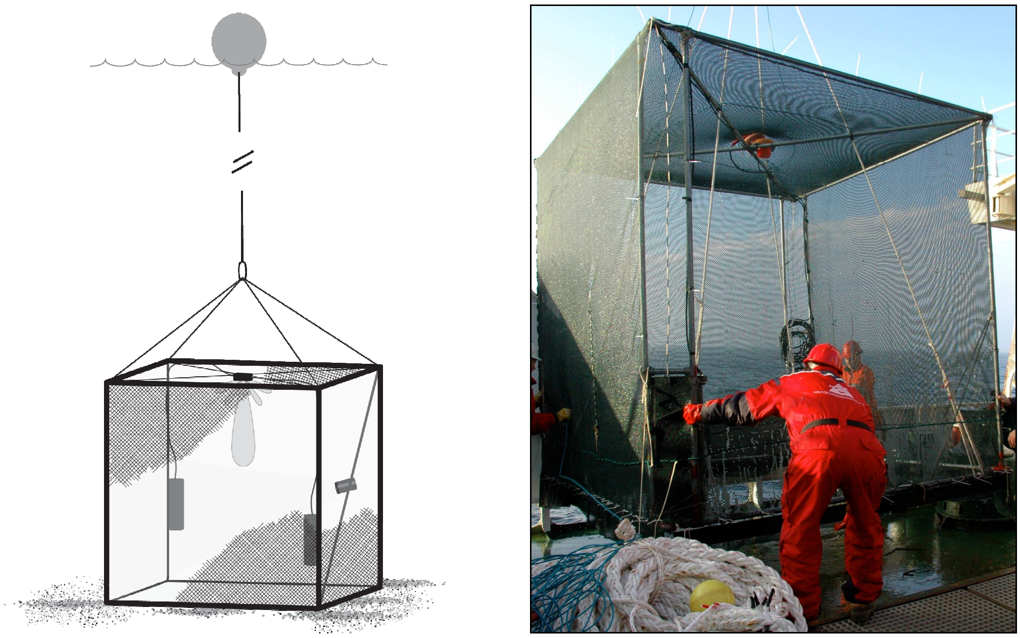


Fig.4. Left: schematic view of sandeel-cage (taken from Svellingen and Ona, 2007); right: photo of the sandeel-cage (taken from data collected on 2007 sandeel survey). Photographer unknown.
4 pav. Kairėje parodytas schematinis tobio narvo vaizdas, dešinėje - nuotrauka.

In 2007, the cage with bottom side open was positioned on the sea bottom during night, aiming to trap the sandeels, which were expected to come out of the seabed in the morning. The plan was that sandeels should swim inside the cage and be targets for the echo sounder and video camera. Both instruments (transducer and camera) were observing only central part of the cage. The position of experimental sites was chosen in areas where daytime survey (trawling, acoustics) showed high abundance of sandeel. To ensure that cage landing during 2007 experiments was successful and data collection will go well, 120m Ethernet cable was connected to the cylinder with main instruments (echosounder, computer). After confirmation that the system performs well, cage was left to work autonomously for 3 periods of 7 to 9 hours each time. According to Simmonds and Maclennan (2005) definition, the experimental method used in 2007 could be called *in situ* TS measurement, but only having in mind some assumptions. Sandeel cage experiments in 2007 were made on fish remainig in its natural environment (no catching, no transportation and following stress), but confined by the cage, meaning free to behave naturally, but not entirely.

Experiment conducted in 2008 was typical *ex situ*. The cage was held in mid-water (at 15-20m depth) for a period of about 6 hours, with all sides covered by net and prior caught fish inside. Sandeels were captured by modified scallop dredge. Fishes were kept in a special metal cubic housing, approximately 1m of a side length. It was equipped with constantly working sea-water pump. Sandeels, used in the experiment were caught in last few days before the experiment, which means the period of fish being in captivity were up to 2 days.

It should be mentioned that sandeel-cage experiments are not finished. Similar, but more concentrated investigations will be done in the 2009 survey of RV "G.O. Sars", May 03-20, 2009.

The control computer and 200 kHz Simrad EK60 echosounder were placed in one pressure resistant cylinder attached to cage frame. It was connected to ES-200-7CD split beam transducer, placed in the centre at the top of the cage. Batteries to power the system were placed in one more separated pressure resistant aluminium cylinder and had enough of power for 48 hours for fully autonomous system work. Transducer, used in sandeel-cage experiments, was designed to have very low side lobe level (namely -52dB), making acoustical instrument extremely sensitive in given conditions. It was possible to record target strength measurements down to -100dB outside transducers near field. Echosounder was set to be working at 0,1/sec fixed ping interval, which is close to maximum ping repetition frequency. It was ensuring the maximum number of detections on sandeel passing trough the beam, but not allowing secondary bottom reflections to occur.

The calibration of split-beam echosounder was done according to standard procedures (Simmonds *et al.* 1984; Foote *et al.* 1987). Depth influence was also taken into account by doing calibrations (Ona and Pedersen, 2006). Detail echosounder settings listed in appendix 1 table 1.

Cage was equipped with Sony HDR-SR1E video camera (with standard night vision) in 2007 and with similar Sony HDR-SR5E video camera in 2008. Video camera was placed in special underwater housing and mounted on one of the cage corner pipes. At the depth of 40m it could record for about 6 hours. Video camera was observing only central part of the cage (tilted downwards, in 2007, rotated up and down in 2008).

2.3 Acoustical data analysis

Experiments on sandeel target strength have been done during North Sea sandeel surveys in 2007 (07.04.25 and 26) and 2008 (08.05.08) with intention and hope to make final experiments in 2009 basing them on experience that is gained already. Experiment design is differing between 2007 and 2008, following this data analysis results are presented separately. At this stage of sandeel TS investigation available data is still quite limited. Because results from two experiments in 2007 (third failed) have some considerable differences, it was decided to present them also separately.

Collected data have been examined in two different ways. Target strength measurements were handpicked manually, isolating data that originated from single objects in water column, objects on echogram that visually were identified as fish. Because of some considerations regarding close distance to fishes on investigation (< 3m), namely accuracy of beam pattern compensation on TS estimates, most precise part of data could be selected. These are TS readings very close to acoustic axis. But this filters out most of data that is limited already. These results are included for better overall understanding of sandeel TS, but not treated independently. Sandeel TS measurements have been handpicked manually from echogram readings. For this purpose part of LSSS (Large Scale Survey System) acoustical data post processing software was used.

Target strength measurements of individual sandeels were done by using single echo detection (SED) method (Handegard *et al.* 2005; Handegard, 2007). SED algorithm is implemented in LSSS (Large Scale Survey System) acoustical data post processing software. LSSS was used for manual handpicking of target strength measurements from echogram.

Single echo detection algorithm is filtering acoustical data ping by ping. The purpose of SED is to accept for further analysis only acoustical data originating from single objects in water column. Single echo detector settings for the target strength analysis are shown in appendix 1 table 2. Single target (fish) passing trough acoustical beam is often detected several times and gives several single echo detections (several TS).

Collected acoustical data can be visualised on echogram, when replayed on special software like EK60 or LSSS. It is possible to identify fish-originating parts of the echogram visually (Fig.5).

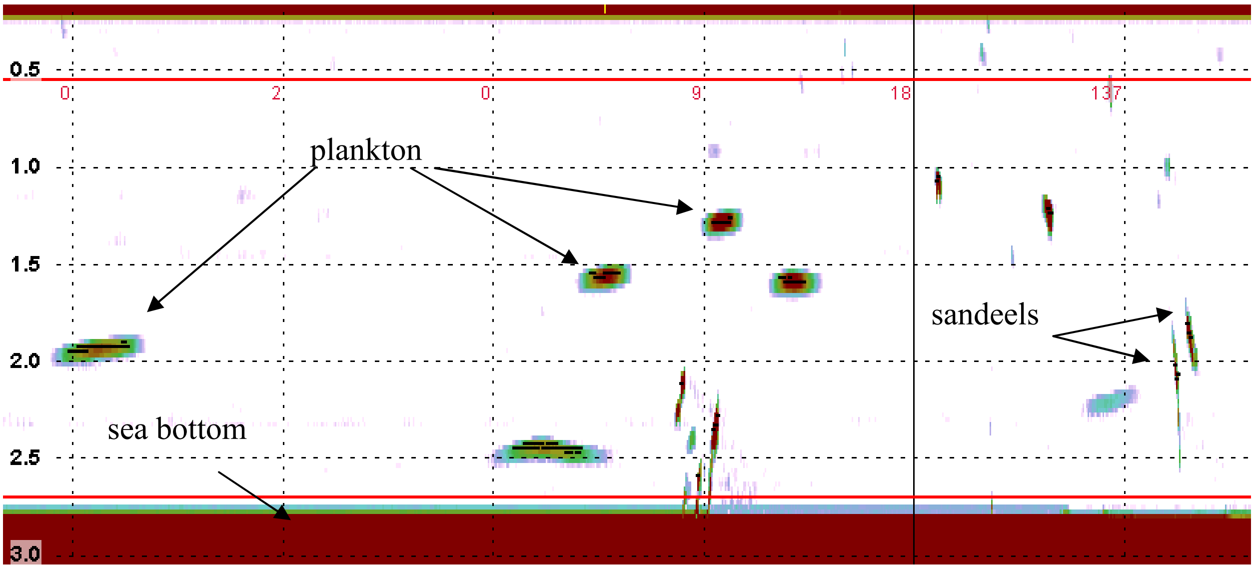


Fig.5. An example how most of the acoustical data collected looks like. 2007 deployment no.2, picture view from left to right accounts for few minutes in time. Short traces are sandeels, long ones show slowly drifting plankton.
5 pav. Pavyzdys kaip atrodo didžioji surinktų akustinių duomenų dalis. Paveikslėlis iš kairės į dešinę apima keletą minučių 2007m antro eksperimento duomenų. Parodyti žuvų ir planktono palikti pedsakai.

Visual identification of what is fish and what is not was based on both: the knowledge about sandeel behaviour gained from video recordings and training (personal communication with Egil Ona). By using LSSS acoustical data post processing software it is possible to sample and save parts of the data manually. Such handpicked sandeel TS measurements were analysed separately on Microsoft Excel software. Information about each single TS detection includes: time, range from transducer, beam compensated target strength (TSC), beam uncompensated target strength (TSU), detection angle athwart ship (α) and detection angle along ship (β). Using TSC backscattering cross sections (б) are calculated for each target strength detection (translation of TS into linear domain), later this is used for averaging the values. Finally the average <б> value is used to gain mean target strength <TS>.

Transducer mounted on the cage was approximately 2.8m above the sea bottom. Data collected just in front of the transducer, had to be excluded, because of near field effects. Near field of a transducer ES200-7CD was calculated to be around 0,53m (personal communication by email with equipment manufacturer SIMRAD). To be certain about the accuracy of the measurements it is often advised to multiply transducers theoretical near field by factor of two. On the other hand, experiments discussed here yielded quite limited data amount, so it was decided to analyse and compare all data outside both: 1 time near field (0.55m) and 2 times near field (1.10m) distance.

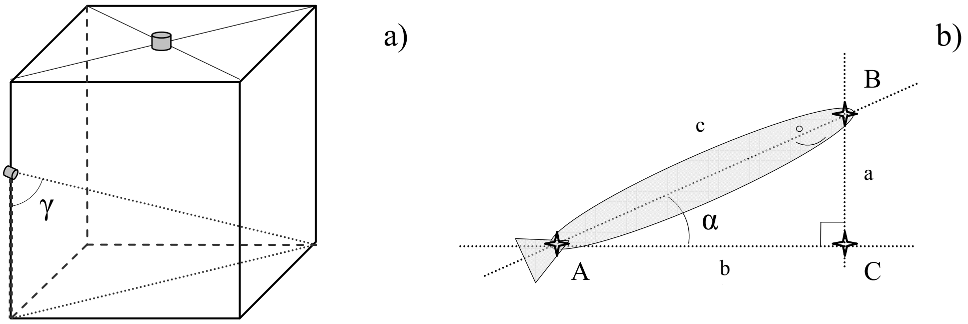
2.4 Video data analysis

Tilt angles were obtained from video data collected during sandeel-cage experiments in 2007 and 2008. Video data was available from one experiment in 2008 and two cage deployments in 2007. In total approximately 2 hours of video recordings from 2008.05.08, 5 and 4 hours from 2007.04.25 and 2007.04.26 respectively were collected. Sandeels were observed throughout all period of the experiment in 2008. Only the last few hours from the recording made in 2007 were containing sandeel recordings. Sandeels are ascending from sediments only in the dawn, while sandeel cage had to be put in place well before this. All recordings were "over-watched" several times in order to spot all appearances of the sandeel. Parts of data containing sandeel images were analyzed using Vegas Pro 8.0 video editing software. Most of the recorded fishes were appearing for a few seconds within camera view. These parts of the video were analyzed frame by frame. In order to get some substantial tilt angle changes in between measurements, 15 pictures per second was taken (some example pictures is shown in appendix 2). The swimming direction was changed drastically by some of the recorded fishes while still being on camera view. However, with curved body shapes by changing swimming direction there was no use to take more pictures per second. After such maneuvers fishes swam out of the view with slowly changing tilt angle. Most of recorded fishes were moving by ≤ 1/3 of the body length in between two sequential pictures. From the first sight useful sandeel images for the tilt angle measurements were filtered out. Approximately 1600 pictures were extracted for the further analysis. After a careful visual examination, frames containing a suitable piece of information on fish tilt angles were selected and processed with ImageJ.

Obtaining fish tilt angles

The important tilt angle of the fish for downward looking echosounder is in a vertical plane. Video camera used for observing sandeels in the sandeel-cage was mounted on the corner pipes of cubic cage, with some height from the bottom (different between 2007 and 2008). During 2007 cage deployments the camera was looking downwards with some angle, with one cage corner in the sight. In 2008 experiment the camera was looking a bit upwards with an easy to be defined angle. In other words, the plane of the camera view was not vertical. This means that fish tilt angles measured on the pictures from a bit tilted camera will be different from the ones in vertical plane.

When knowing the angle camera is tilted with it is possible to calculate the actual tilt angle of the fish in vertical plane. The angle of the camera tilt from straight downward (this angle was actually needed in 2007 data analysis) or straight upward looking position (2008) can be estimated by knowing dimensions of the cage, camera position (height) on the corner pipes, some point of the cage that is in the camera view and the approximate opening angle of the camera view. In 2007 experiment, the bottom corner of the cage is conveniently in the central part of the camera view, camera is fixed and does not move during the whole experiment (Fig.5a). In order to observe sandeel behaviour within all parts of the cage the camera was rotated a few times upwards and downwards during the 2008 experiment. The camera tilt angle could be defined with all sandeel pictures that were used for the analysis.



Picture 5. a) schematic view of the sandeel cage with video camera mounted on corner pipe (2007), angle γ represents camera tilt angle from the straight downward looking position; b) rectangled triangle ABC, hypotenuse c is also a line drawn trough upward swimming fish head and tail mid-points, meaning fish body “axis”.
5 pav. a) schematinis narvo vaizdas su video kamera, įtaisyta ant kampinio vamzdžio (2007), γ *yra kameros polinkio kampas; b) statusis trikampis ABC, kurio įžambinė c yra taip pat ir žuvies kūno „ašis“.*

The following description of the fish tilt angle estimation in vertical plane will be presented ass it was used for the 2007 data analysis. For 2008 data the principle is the same, but calculations differ due to the different inclination of the camera. So let’s say, that the investigated fish is swimming with some body tilt angle upwards (positive angle) and in the appropriate direction for taking qualitative images on tilt angle, meaning not towards the camera or outwards. A rectangled triangle should be imagined, where hypotenuse (c) of the triangle is a part of the line drawn trough the mid-points of the fish head and tail (Fig.5b).

The triangle ABC is in a vertical plane, accounting to the fish body’s tilt angle. It is important for downward looking echosounder that is present above the fish. In other words it could be told, that the fish body tilt angle from the horizontal position one of ABC triangle acute angles α is the goal, the fish body tilt angle from horizontal (Fig.5b). It could be obtained by drawing two lines (one – the axis of the fish body and the other exactly in a horizontal position) on a suitable picture post processing software. But video camera recording images of this fish was tilted downwards, meaning it ‘sees’ the fish in a slightly different than vertical plane (triangle ABC cannot be seen and investigated directly).

On the other hand, the same type of an imaginary rectangled triangle A_1BC_1 could be drawn with a fish seen on the camera picture, just in a slightly different plane (Fig.6a). Triangle A_1BC_1 is in plane for video camera and fish in its hypotenuse A_1B represents how the real fish from ABC plane would look like. Part of line drawn trough fish body axis will be hypotenuse of this right triangle as well. The length of the triangle bottom leg will be the same as in the vertical plane, which means, that $AC=A_1C_1=b$. But the length of the other leg will differ (in this case $a_1<a$). The length (in relative units, pixels) of a_1 and b can be obtained from the video camera recordings. This could be achieved by relating these known values with the length a (which is seen on pictures indirectly, trough a_1), the fish body tilt angle in vertical plane (angle α) can be estimated using by simple triangle geometrics.

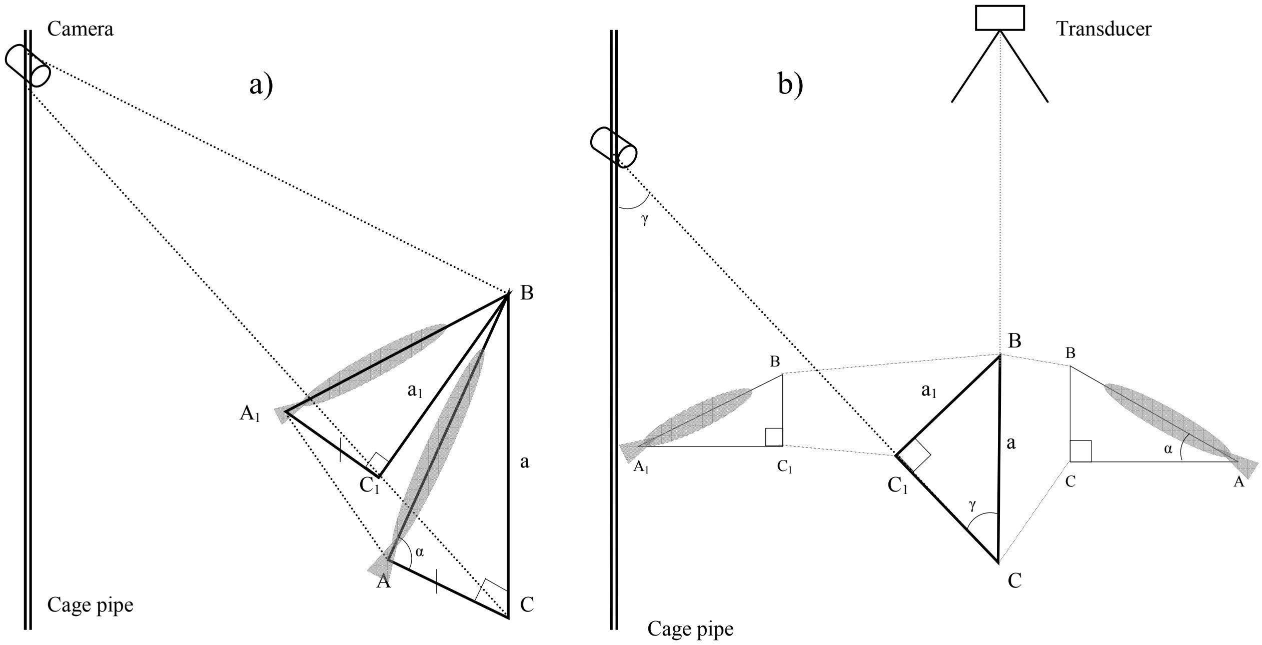


Fig.6. a) two rectangled triangles in different planes. ΔABC is in a vertical plane with a real fish on its hypotenuse AB and ΔA_1BC_1 is in a plane of the tilted camera view; b) the same right triangles are shown in different aspect, with attention to the third right ΔBC_1C in-between first two; the angle $<BCC_1$ is equal to γ.
6 pav. a) du statieji trikampiai pavaizduoti skirtingose plokštumose. ΔABC yra vertikalioje plokštumoje, jo įžambinė – žuvies kūno „ašis“, ΔA_1BC_1 yra kampu žemyn pakreiptos video kameros vaizdo plokštumoje; b) tie patys statieji trikampiai parodyti kitu aspektu, dėmesį atkreipiant į trečiąjį statų ΔBC_1C išsidėsčiusį tarp pirmųjų dviejų, kampas $<BCC_1$ yra lygus γ.

Rectangled triangles ABC and A_1BC_1 are positioned in space in such a way that triangle BC_1C located between them is also rectangled, its’ right angle is $<BC_1C$ and the extension of CC_1 is a line reaching video camera view. This line has the same angle from the vertical position (or horizontal one) as the camera tilt (Fig.6b). That is to say, the angle γ (the estimation of γ is discussed in chapter below) is equal to angle $<BCC_1$, because the cage pipe with the mounted camera is vertical and parallel to BC, which is a part of the triangle ABC in vertical plane.

According the sinus theorem:

$$\frac{a_1}{\sin\angle B\,CC_1}=\frac{a}{\sin\angle BC_1\,C} \quad \text{or} \quad \frac{a_1}{\sin\gamma}=\frac{a}{\sin 90^\circ} \quad \text{and} \quad a=\frac{a_1}{\sin\gamma}, \qquad (3)$$

where a_1 is measured from the camera picture, γ is previously estimated camera tilt.
Length of a_1 and b could be obtained using x and y coordinates of the A_1 and B points (in the numbers of pixels).

Afterwards it is possible to come back to Fig.5b, where a and b are already estimated, and c is easy to be estimated from Pythagorean Theorem. Therefore, according to the sinus theorem, the sinus of the fish tilt angle α will be:

$$\frac{a}{\sin\alpha}=\frac{c}{\sin 90^\circ}\Rightarrow \sin\alpha=\frac{a}{c}. \qquad (4)$$

All these calculations are quite simple and could be placed in Microsoft Excel work sheet. The input numbers are length b and a_1 that have to be measured using special picture editing software together with camera tilt γ, which is previously estimated. Output is fish tilt angle in the vertical plane.

The camera tilt

The camera tilt and the view opening angle were different in 2007 and 2008 experiments. The camera tilt angle estimation for 2008 data will be described firstly. In all of the analyzed sandeel pictures form the 2008 experiment camera was looking upwards with some angle, it was also rotated up and down several times. According to this, the camera tilt angle had to be defined also several times. In all of the analyzed sandeel pictures, the upper corner of the cage was seen and was used as a reference for camera tilt calculations. It is known that camera was mounted at a height of 0.7m from cage bottom on one of the corner pipes, which means that 2m of the pipe was left above. The diagonal of the cage top square is $2.8\sqrt{2}$ m. These two segments are the legs of the right triangle. One of triangle acute angles is the camera tilt angle from straight upward looking position. The gained value is ~63.2º. This is the camera angle towards one of the cage upper corners, which is present in all of the analyzed sandeel pictures. Nevertheless, this camera tilt angle can not be used for sandeel appearances in different parts of the picture equally. The camera view opening has also an angle and the camera tilt is known only by one point in camera view (the previously mentioned cage corner). Video camera view opening angle has to be defined.

It was done in two ways. The actual camera used in cage deployments and with the same zoom was taken and a simple experiment was performed. A ruler was attached to the wall and the camera was put in front of it at the distance of exactly 1m (Fig.7a). Camera was lying in a horizontal position. The taken pictures were analyzed with ImageJ and the camera opening angle was estimated using triangle geometrics. The gained value was ~28.4º.

Second and the rougher estimation were done by using the actual video data on the analysis. Camera position in the corner pipe is known (0.7m). On one of the cage sides there was a net rip for the opening and closing, entering the cage. This rip was placed approximately in the middle of the cage side, this means, that at the distance of 1.4m from the corner pipes. The rip length is of 2m, what is almost exactly fitting the extent of the camera view opening. By knowing measurements of the cage and the discussed measures it is therefore possible to calculate approximate video camera view opening in degrees. It was calculated to be approximately of 33-35°. Some uncertainty in the cage dimensions that were used has to be taken into account. For example, the cage net rip is of 2m in total length when stretched and measured, but when on the cage it is a bit collapsed and for this reason it should be shorter. Shorter net rip length would reduce camera view opening estimation. The value of 28.4° was taken and used in the further calculations.

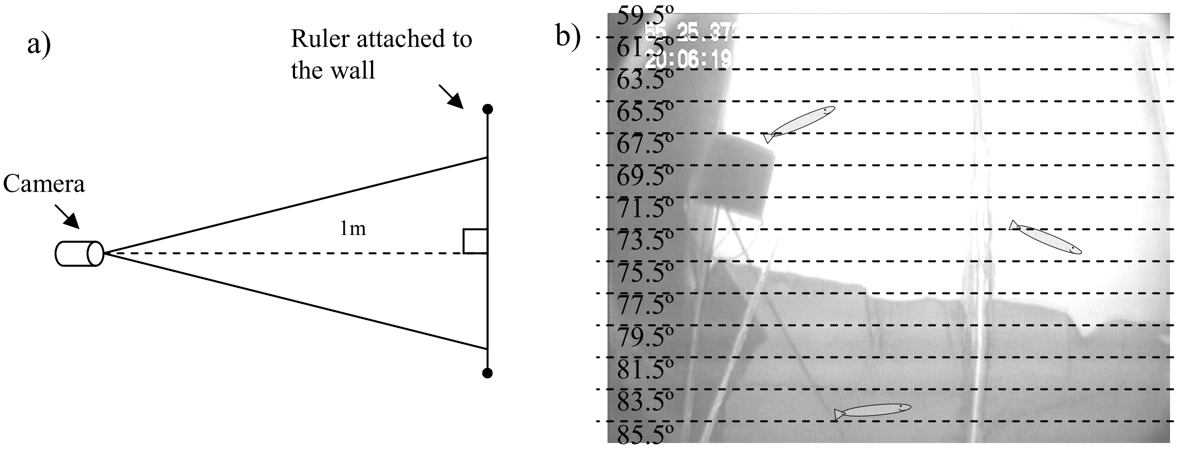


Fig.7. a) a simple drawing describing an indoor experiment. The aim is to examine the camera view opening angle; b) sandeel cage experiment in 2008. Estimated approximate camera opening angle is shown, it is presented by camera tilt angles from upward looking position.
7 pav. a) schema, apibūdinanti eksperimentą, daryta siekiant nustatyti kameros matomo vaizdo vertikalų kampą laipsniais; b) 2008 metų tobio narvo eksperimento video duomenų apdorojimas. Parodytas kameros rodomas vaizdas ir jos polinkio kampas laipsniais.

The known camera tilt angle to cage corner point in the sight was used as a reference. Then by knowing the extent of pictures in vertical what can be defined in pixels (1080 pixels), it is possible to calculate camera view angle to some points in very top and very bottom of the picture. In this way camera view opening angle is defined for all vertical extent of the picture. Now picture was split in 14 stripes or areas. Each is accounting for some 2° of camera tilt angle (Fig.7b). The boundaries of single stripe were defined by number of pixels vertically. Finally the value of camera tilt actually used for fish found in this picture area or stripe was the middle of these 2°. In this way accuracy of camera tilt angle value used at this point of calculations is ±1°. Because position of each fish in picture and boundaries of each stripe is characterized by numbers of pixels, it was easy to attribute fish to one of camera tilt angles. Furthermore by being able to use 14 possible camera tilt angles in single picture, the error at this stage of fish tilt angle estimation is greatly reduced. By changing camera tilt angle input in fish tilt angle estimation equations by ±1° it was discovered that fish tilt angle should be under or overestimated no more than by 0.1-0.2°.

In 2007 sandeel cage experiments video camera was tilted downwards. Camera was mounted also on one of the cage corner pipes at approximately 1.4m height. Looking bit downwards almost straight to one of the cage corners. Camera tilt from straight downward looking position was calculated in the same way as was described for 2008 experiment, meaning as one of acute angles of right triangle, which's legs are 1.4m and $2.8\sqrt{2}$ m. Gained value is ~70.5º. This is a camera tilt from downward looking position to almost very middle of the camera view. It is clear that camera was with higher zoom mode in 2007 experiment than in 2008, meaning the view opening angle was smaller. But even some adjustment of camera tilt angle value used by examining fish in top or bottom of the picture will reduce the error of fish tilt angle estimate.

Camera view opening angle in 2007 was estimated by using a battery cylinder diameter as distance reference. It was present in very corner of cage and seen on video recordings. Battery cylinder diameter is 29.8cm, so distance from the camera till middle of the cylinder is just some 15-20cm less than till cage corner. By using cylinder diameter as length reference it is possible to estimate approximately what would be the vertical length of an object that just fitting in camera view at the distance equal to distance from camera eye till the battery cylinder. In other words it is quite the same calculation like presented in Fig.7a only the length till the wall will be not 1m, but 4.2 minus cylinder diameter. Gained value is approximately 15º. It was used in same manner like it is described for 2008 video data analysis. By using picture vertical extent measured in pixels (1080) and dividing picture vertically in 7 stripes, each accounting for 2º (bottom and top ones for 2.5º). The value of camera tilt used for fish found in particular picture area (stripe) was the middle of these 2º (2.5º).

Considering fish position in-of plane

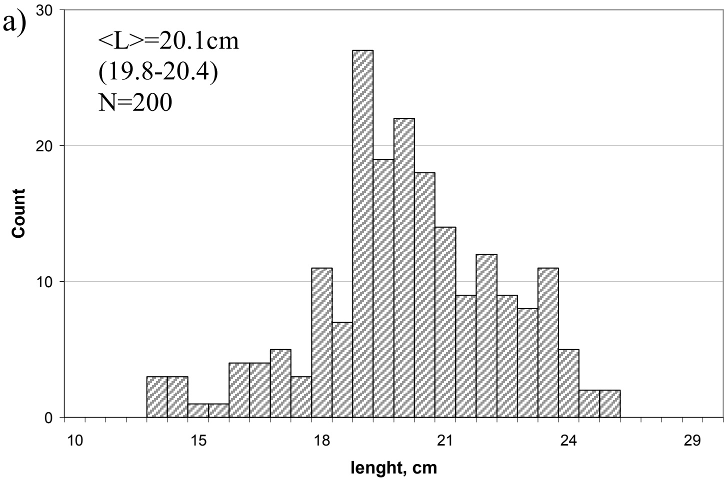
The best pictures for tilt angle estimations are when fish is completely in a plane of the video camera view, meaning sandeel tail and head is having the same distance from camera. Of course sandeels not always were swimming in such a favorable direction trough camera view. It was assumed that it is possible to distinguish with a naked eye the fish images, where sandeel body is appearing in no more than 10-20 degrees of the exact plane for a camera view. Such of-plane angles make some difference in tilt angle measurement from the pictures. It was tested empirically. A 3 dimensional object (made from metal wire) that has a known tilt angle was put at a number of positions in video camera sight, first by being in plane for it, later with 10 and 20 degrees of plane. Camera was put at actual position (1.4m height, 3.96m from room corner) and with the same tilt angle like in 2007 sandeel-cage experiment, but in office. Results showed that method works very well with fish in plane for the camera, but under or overestimation of fish tilt angle increases largely with higher of-plane angles. When fish is with some angle of plane by swimming outwards from the camera tilt angle is overestimated and underestimated when towards; in opposite when camera is tilted upwards. Experiments with an object in plane gave measurements within some ±0.5º (n=10) from real tilt angle value. When object was put 10º of plane results were about ±1.5-2º (n=10) from real value and with 20º of-plane angles it increased to about ±4-5º (n=10). Few measurements were made with object about 30º of camera plane and yielded error was up to 10-11º. On other hand it is easy enough to see even with naked eye when the fish is 30º of plane. Only pictures with fish appearing less than 20º of plane (visual examination) were picked up for tilt angle measurements.

With fish perfectly in-plane for the camera A_1C_1=AC (Fig.6), which is crucial for the method described to be valid. Fish off-plane orientations induce an error as A_1C_1 becomes less than AC. However, it is rather small with fish of 20cm or less at range of 1 to 3m and fish off-plane angle being less than 20º. This error was considered when calculating the overall accuracy of the sandeel tilt measurements in these experiments.

3. RESULTS

3.1 Collected biological data on sandeel

Sandeel-cage had no closing device when put on the sea bottom in 2007 experiments and the sandeels were not collected for the direct measurement of body length. Though, fish length distribution had to be obtained in a different way. Catches by trawling and dredging in the vicinity of the experimental site were used to gain sandeel size distribution. The mean fish length measured was 20.1cm with 95% confidence interval in between 19.8–20.4cm (Fig.8a). Because of the fairly narrow size distribution in catches obtained around deployment sites it was assumed to be representative to sandeels observed inside sandeel cage during the experiments.



b)

Fish No.	Weight[g]	Length[cm]
1	7.5	13.5
2	6.2	12.0
3	4.6	11.0
4	6.2	11.5
5	6.7	12.5
6	5.2	12.0
7	6.2	12.5
8	8.1	13.5
9	8.2	15.0
10	8.0	14.0
Mean	6.7	12.8

Fig.8. a) sandeel length distribution obtained from trawl and modified scallop dredge catches close to 2007 sandeel-cage deployment sites, mean length with 95% confidence interval is shown (drawn using 2007 sandeel survey data); b) table showing length and weight of sandeels used in 2008 sandeel-cage TS experiment (taken from 2008 sandeel survey data).

8 pav. a) tobio kuno ilgio pasiskirstymas apie vidurkį. Žuvys sugautos žvejojant tralu ir modifikuota draga netoli 2007 metų tobio narvo eksperimentų vietos; b) lentelė, rodanti 2008 metų eksperimento metu naudotų žuvų ilgį ir svorį.

2008 sandeel-cage experiment was performed by using captured fish in totally enclosed cage. Length distribution and weight of fish was easy to determine. A subsample of sandeels used in the cage was measured and weighted (picture 8b).

3.2 Sandeel target strength

Analysis of data from two 2007 experiments and one 2008 experiment are presented below. For the sake of simplicity from now and onwards acoustical data set from 2007 experiment no.2 (07.04.25) several minutes after cage landing will be referred as D2L, data part later on/after landing moment will be called D2, in the same way two data parts from deployment no.3

(07.04.26) will be identified as D3L and D3 respectively. Finally acoustical data set and associated results from 2008 cage experiment (08.05.08) will be called 08D.

2007 sandeel-cage experiments

Data from both 2007 sandeel-cage deployments was divided in four parts: the data obtained during landing moment, which accounts for the first several minutes after cage reached the sea bottom (D2L, D3L) and the rest of the data obtained till cage was lifted up (D2, D3). On both acoustical data sets from 2007 it is lot of targets detected in first few minutes just after cage landing (Fig.9).

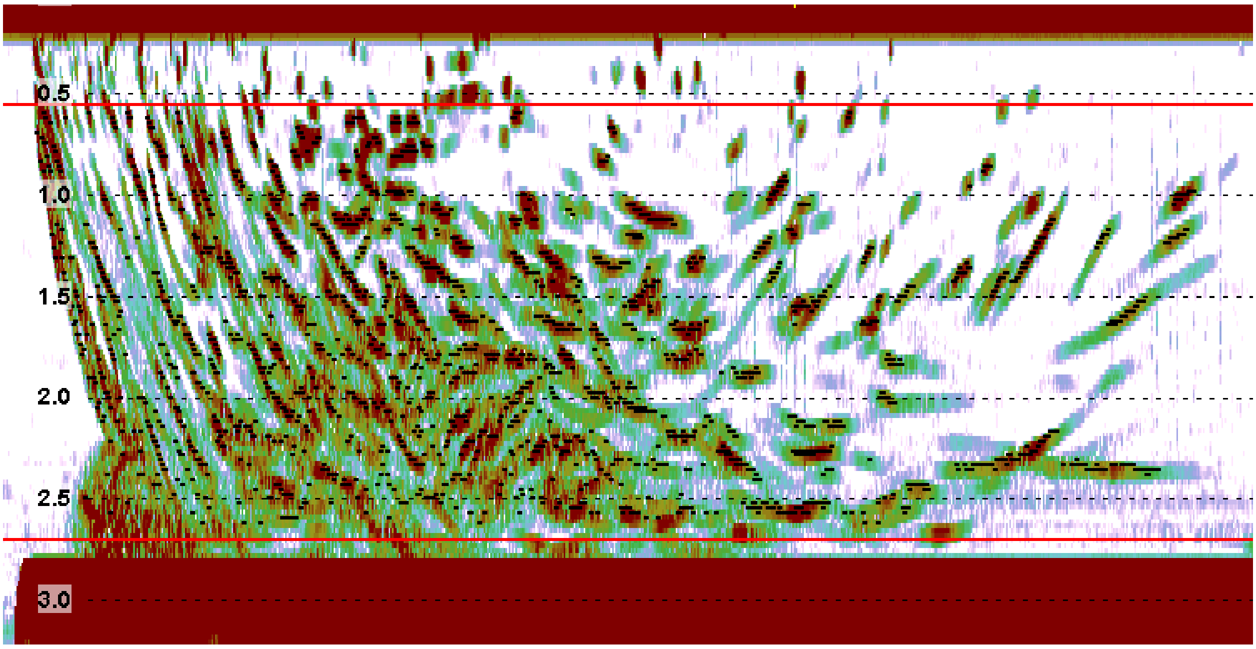


Fig.9. 2007 deployment no.3 acoustical data, several first minutes after sandeel-cage landing (D3L) as visualized on LSSS. Many of traces in upper right quarter of the picture are originating from sandeel. Black marks are indicating individual target strength measurements.
9 pav. 2007m trečio eksperimento akustiniai duomenys, keliolika pirmųjų minučių, narvui pasiekus dugną (D3L). Daugelis objektų, matomų paveikslo viršutiniame dešiniame ketvirtyje yra tobiai. Juodi taškai žymi atskirus akustinio atspidžio (TS) matavimus.

These are expected to be some planktonic organisms collected on upper cage side net on the way down and sinking after cage landing as well as disturbed sandeels that came up from sediment and was rapidly swimming back and forward inside the cage (giving lot of targets for echosounder). Landing moment data contains lot of sandeel TS readings, but also was hard to read and handpick fish-originating target strength data (Fig.9). This means that handpicked TS measurements can contain some plankton target strength readings. Because plankton is expected to have generally lower TS than sandeel, average sandeel TS obtained from acoustical data just after cage landing could be biased towards lower values because of the inclusion of TS originating from plankton animals. Furthermore, fishes disturbed by cage landing could be expected to swim with unnatural tilt angles, meaning average TS can differ from TS obtained from data collected later on.

Near field of transducer used was calculated to be 0.53m (section 2.3). On other hand, it is often advised to use double near field, to get best quality data. Having in mind limited data amount TS measurements were handpicked at both distance intervals (0.55-2.70m and 1.10-2.70m) and are summarized in Fig.10.

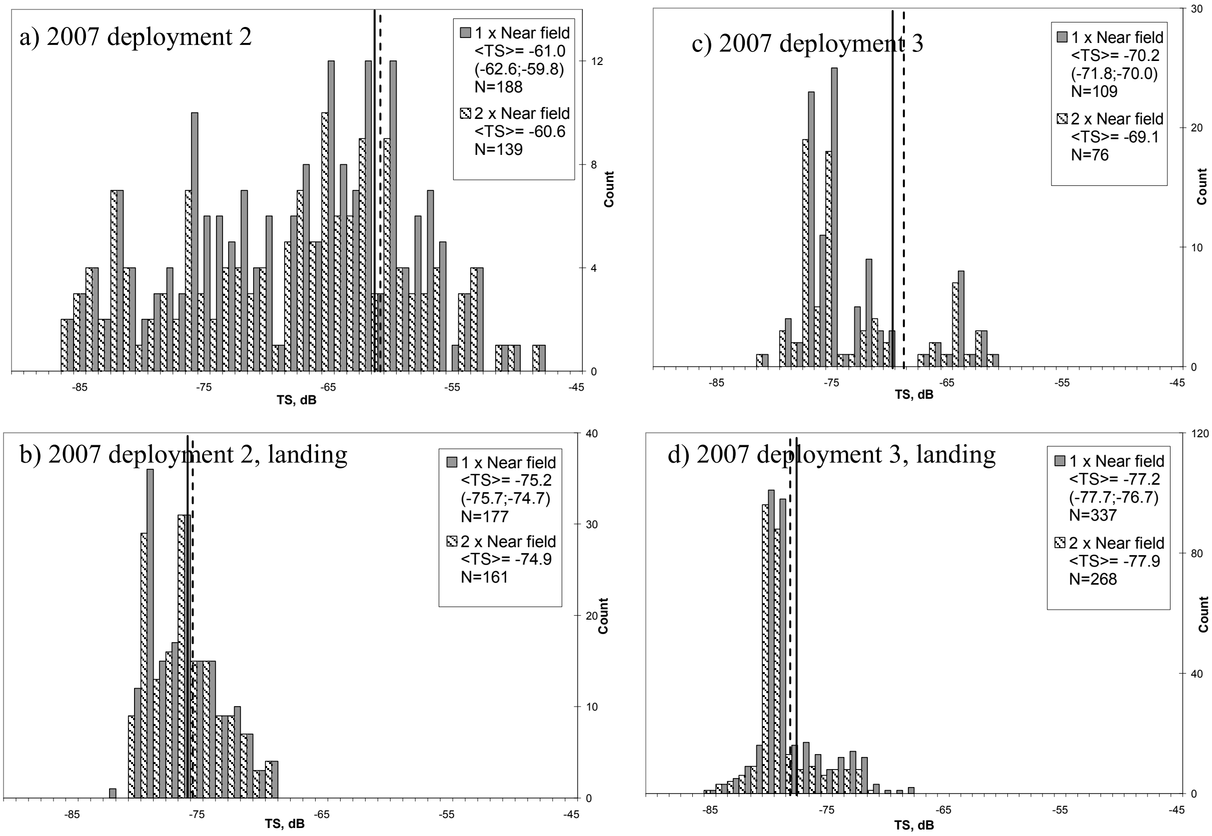


Fig.10. 2007 sandeel-cage experiments no.2 and no.3. Sandeel target strength [dB] distribution, handpicked at 0.55-2.70m (1x near field) and 1.10-2.70m (2x near field) down below the transducer. a) and c) show second and third deployments, TS measurements from D2 and D3; b) and d) show second and third deployments, TS measurements from D2L and D3L. Solid and dashed lines represent mean TS from 0.55-2.70m and 1.10-2.70m layers respectively. In the text box: <TS> - mean target strength, 95% confidence interval in brackets, N – sample size.

10 pav. Tobio akustinio atspindžio stiprumo (TS) matavimų pasiskirstymas apie vidurkį. Rinkta rankiniu budu – atskirai 0.55-2.70m ir 1.10-2.70m sluoksniuose iš 2007m antro ir trečio eksperimentų duomenų.
a) ir c) parodyti atitinkamai 2 ir 3 eksperimentų TS matavimai iš D2 ir D3 duomenų; b) ir d) parodo TS matavimus iš D2L ir D3L duomenų. Vientisa ir punktyrinė linijos žymi vidutinius TS.

It was no statistically significant difference between mean TS calculated excluding data from water layer closer than single near field distance of transducer (<0.55m) and excluding double near field distance (<1.10m) for data sets D2, D2L and 08D ($p<0.05$, Wilcoxon test of signed ranks). For D3 and D3L data sets it was statistically significant, with difference in <TS> 1.1dB and 0.7dB respectively. However, these differences are relatively small, if wide scattering of mean TS measurements are to be considered. All the following numbers are presented as result of excluding data from 0.55m in front of transducer, what accounts for single transducers near field.

Handpicked mean TS from D2 data was -61.0dB (Fig.10a). This was significantly higher <TS> than one calculated from third deployment as well as landing data in both deployments.

Target strength measurements picked up close to transducer acoustical axis (≤ 1° of axis) yielded <TS> of -59.4dB (n=14).

Analysis of D3 data (Fig.10c) gave mean target strength of -70.2dB. Clearly bimodal distribution of measurements can be seen. Here close to acoustic axis <TS> was -71.6dB (n=8), what was also not very far from overall D3 data set mean TS.

TS handpicking from part of the data just after sandeel-cage landing in both successful 2007 experiments yielded relatively low <TS> estimates. Mean target strength estimate for D2L is -75.2dB (Fig.10b), meaning 14.2dB lower than from D2 data. TS measurements picked up closer than 1° from acoustic axis gave mean value of -73.6 (n=16).

In a similar manner handpicked <TS> from D3L data is -77.2dB, what was lower than mean TS gained from D3 (-70.2dB). Mean target strength from readings close to acoustical axis (≤ 1°) was -77.7dB (n=31), what again was quite close to <TS> gained from data collected across entire acoustic beam.

It was more difficult to recognize and handpick sandeel originating TS measurements in deployment no.3 data just after cage landing than in D2L. It is possible that by handpicking D3L data more plankton TS readings were miss-interpreted and accepted as sandeels. Beginning of data set from experiment no.3 was more difficult to read and handpick than acoustical data just after landing in deployment no.2 (D2L). If so, <TS> from D3L can contain more plankton TS measurements and mean sandeel target strength obtained from this data set can be biased toward lower values because of low plankton target strength. However, it is also possible that D3 result of mean TS is affected by some non-sandeel fish recordings, what is expected to pull resulted mean up.

Non-sandeel fish was present inside the cage during third deployment 2007. Most probably it was some flatfish. It was easy to spot, because of quite different pattern seen on echogram than commonly interpreted as sandeel and much higher TS readings (-43 to -47dB). This part of data was excluded. Mentioned fish was not seen on video recordings.

Significantly higher mean TS was calculated from D2 data than was gained from D2L, D3, D3L, as well as 2008 cage experiment (see following section) data sets. It is considered as a possibility that some small and hard to spot on echogram flatfish(-es) was present inside the cage during second experiment 2007 and are responsible for high TS measurements in right tail of TS distribution in Fig.10a.

2008 sandeel-cage experiment

Sandeel-cage has been used again during 2008 sandeel survey. Experiment design was different: enclosed cage with sandeels captured in advance was held in mid-water on a line. This ensured that only sandeels were present in the cage and more of them than was found resting in sediments by putting cage on the sea bottom in 2007. It was expected that much more sandeel TS measurements will be obtained in relatively shorter time. But also some difficulties were met. More sandeel TS measurements were obtained per time period than in 2007 experiments, but less than it was expected. Most of the fish tend to swim in the upper part of the cage, which is outside the acoustical beam. Experiment was successful, but the collected data were still limited.

All target strength measurements during sandeel-cage experiment in 2008 were treated as one data set (08D). The experiment wasn't divided into separately analyzed periods like it was with 2007 data. Handpicked TS measurements are summarized in Fig.11.

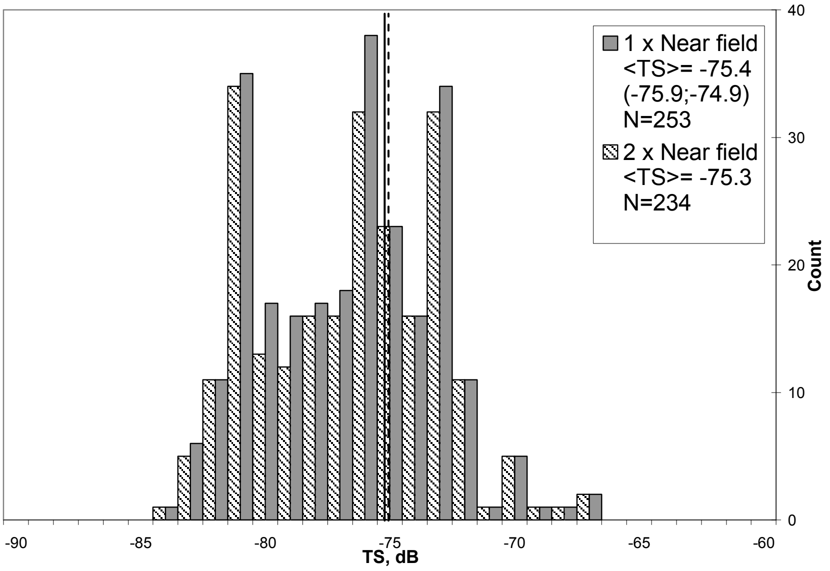


Fig.11. 2008 sandeel-cage experiment. Sandeel target strength [dB] distribution, handpicked at 0.55-2.70m (1x transducer near field) and 1.10-2.70m (2x near field) down from the transducer. Solid and dashed lines represent mean TS from 0.55-2.70m and 1.10-2.70m layers respectively. In the text box: <TS> - mean target strength, 95% confidence interval in brackets, N – sample size.

11 pav. 2008m tobio narvo eksperimentas. Tobio akustinio atspindžio stiprumo (TS) matavimų pasiskirstymas apie vidurkį. Rinkta rankiniu budu atskirai 0.55-2.70m ir 1.10-2.70m vandens sluoksniuose po echolotu. Vientisa ir punktyrinė linijos žymi vidutinius TS.

Mean sandeel target strength yielded after manual handpicking using LSSS is -75.4dB, with quite narrow 95% confidence interval. Target strength measurements handpicked up to 1^{o} of acoustic axis gave <TS> of -75.9dB (n=22).

Some conditions regarding manual TS handpicking have to be mentioned. In 2008 sandeel-cage was held on a line aside the ship at some depth during calm weather conditions. But still some effect of wave action (up and down movements) was noticeable on video recordings as well as on acoustical data. It was more difficult to identify fish tracks on echogram than it was with sandeel-cage stationary lying on the sea bottom in 2007. So in a way this set of data and resulted <TS> can be treated like 2007 results gained form data just after cage landing (D2L and D3L). In other words with some caution on miss-interpreted plankton TS readings which were possibly included in the measurements.

Size-dependence of sandeel target strength

It is often that results of target strength experiments are presented and expressed as TS and fish body length relationship: $TS=20*\log_{10}(L) + b_{20}$, where L is mean length of the fish, b_{20} is species dependant and called reduced target strength. Because D2 mean TS was considered as less reliable, it was not used for the computation of this relationship equation. The equation for results presented is the following one:

$$TS = 20*\log_{10}(L) -99.7 \qquad (5)$$

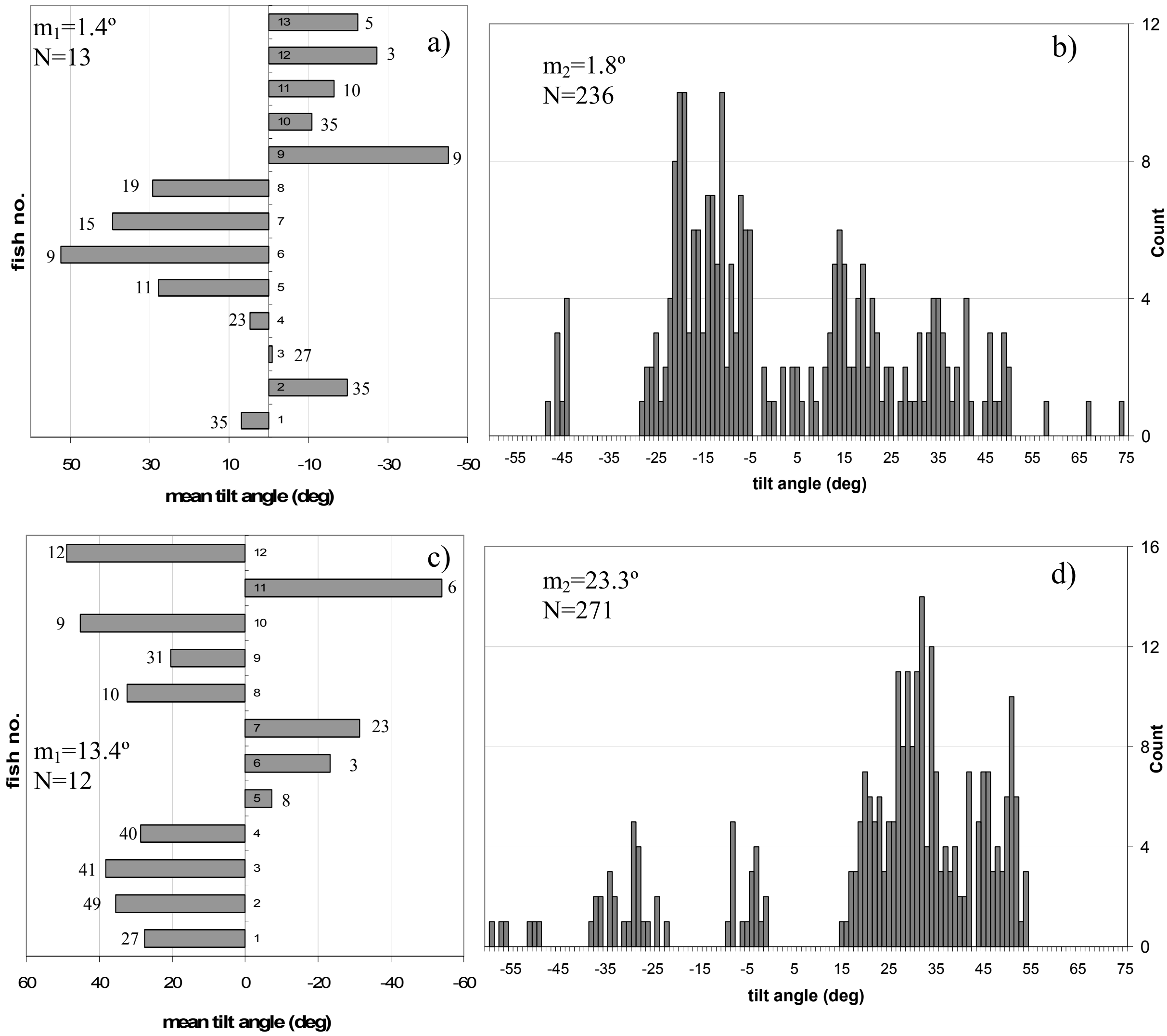
This relationship is shown as solid line in Fig.13.

3.3 Sandeel tilt angle estimation

Aproximately 1600 pictures which could be potentially used for the tilt angle measurements were extracted (from 2007 experiment no.2 and 2008 video data). After carefull visual examination for fish in-of plane position 507 pictures were selected and processed using ImageJ photo editing software. Sandeel body tilt angle estimations were done according technique developed here, successfuly tested by measuring tilt of an object with known tilt angle and described in section 2.4. As it is seen form figures in Fig.12, quite different sandeel mean tilt angle were gained from 2007 and 2008 experiment data. Sandeel body tilt angle was calculated as two values and called $m_{1,}$ means of tilt angle measurements per fish summed and divided by number of fish, and m_2, mean of all single tilt angle measurements (picture by picture).

For fish recorded in 2007 m_1 and m_2 are close to each other and slightly positive, 1.4° and 1.8° respectively. Single tilt measurements of m_2 are spread in-between -1.3° and 4.9° or ±3.1° (95% confidence interval) and with standard deviation of 24.1. 2008 video data analysis gave higher positive tilt angles of the fish. Mean tilt angle m_1 was calculated to be 13.4°. Mean tilt angle from all single measurements m_2 is 23.3°. 95% confidence interval for m_2 is from 20.3° to 26.3° (±3.0°). Standard deviation of measurements around m_2 was again high and equals to 25.4. In this case m_2 or mean of all single sandeel tilt angle measurements is considered to be more important to look at. It is not too many single fishes seen and examined. For echosounder the fish "incident tilt angle" is important at every ping (e.g. 0,1/sec ping interval was used in this study). Because of the fact that sandeel target strength was averaged across all single TS measurements, it makes sense to treat sandeel tilt angle measurements in same way.

The difference in mean calculated tilt angle between two sets of data (from 2007 and 2008) is clear, however not unexpected.



Picture 12. Results on sandeel tilt angle from 2007 deployment no.2 (a and b) and 2008 (c and d) experiments are presented. a), c) mean tilt angle of each fish and number of measurements per fish are shown, as well as mean m_1. b), d) figures show distribution of all single tilt angle measurements, m_2 is a mean and N is total number of accepted tilt angle measurements,

14 pav. Pristatomi tobio kūno polinkio kampo matavimų rezultatai. a) ir b) rodo 2007 antro eksperimento, o c) ir d) rodo 2008 eksperimento duomenų analizę. a) ir c) parodytas vidutinis kiekvienos fiksuotos žuvies polinkio kampas, matavimų skaičius, taip pat nurodytas vidurkis m_1 *bei bendras žuvų skaičius. b) ir d) paveikslai rodo visų atskirų tobio kūno polinkio matavimų pasiskirstymą,* m_2 *– jų vidurkis, N - matavimų skaičius.*

Unfortunately analysis of video made during 2007 deployment no.3 yielded no sandeel tilt angle measurements. Some fish were observed by video camera, but with unfavorable, of plane angles or still in dawn darkness by making it hard to define contour of the fish and it's of the plane position.

4. DISCUSSION

4.1 Sandeel mean target strength

In total of three experiments the sandeel target strength was measured and analyzed. Data coming from first two experiments (2007) was split into four data sets (D2, D2L, D3, and D3L). It was done because of different conditions during the collection of the data. Finally 5 mean target strength estimates were gained. The results are presented in Fig.10 and Fig.11, as well as in Fig.13. But first possible error sources in mean target strength estimates have to be discussed. Some of them could be caused by the low abundance of fish used during the investigation, possibility of registering targets other than sandeel, by calibration and collection of acoustical data close to the transducer.

Echosounder calibration was performed before both: three 2007 experiments and the 2008 experiment. It was done using a tungsten carbide sphere according to well established standard measurements (Foote *et al.* 1987; Ona (ed.), 1999) and is considered to have minor importance with respect to errors in target strength. However, there are some considerations regarding the close distance to the targets in this investigation. When target strength is measured close to the transducer and off acoustic axis, there is a possibility that TS compensation for the beam pattern effects is incorrect. During all sandeel-cage experiments sandeels were recorded in distance less than 3m in front of the transducer. On other hand, all measurements were still done outside transducer near field distance: first, outside the double near field distance, then later outside single near field distance, in order to obtain more data. It was also tested, if significant differences in mean TS were recorded between these ranges. No significant differences were found for D2, D2L, and 08D ($p<0.05$). It was significant for D3 and D3L, but actually not very large (1.1 and 0.7dB). At this point of sandeel TS investigation the collected data are limited and with quite widely scattered estimates of mean TS. Differences in <TS> estimates outside single and double near field distance should be kept in mind, but not overlooked. Furthermore, to clear the doubts it was tried to pick up TS measurements very close to acoustic axis ($\leq 1^{o}$), where almost no compensation for beam pattern is needed. Again significant, but in given situation relatively small difference in <TS> was seen (0.5-1.6dB). Although it has to be said that the number of TS measurements close to acoustic axis was small, which could explain the difference and prove the accuracy of TS compensation in these experiments on one hand, but in general the data cannot be used for proving this.

The abundance of fish during the TS measurement experiments is relevant for the discussion. Sandeel is a schooling fish and if sandeel is to be surveyed with acoustic devices for direct or index-based abundance estimation, schools are the quantities/‘units’ to be recognized and measured, rather than individual fish. From this point of view the low abundance of sandeels found inside the cage during all the experiments was not suitable to assess the schooling behavior. Mean TS measured from the single sandeel individuals could differ from TS obtained from sandeel schools, due to their body orientation pattern. But it has to be stated that sandeel is very complicated species to investigate acoustically and these experiments are just one of our steps in understanding sandeel's target strength. There are many fish species that we do not know the exact TS; some of them have been surveyed acoustically for many years. Still it is desirable to obtain and use numerical values of backscattering which are as close to real TS as possible.

When sandeel cage was dropped to the sea bottom in 2007, it was not equipped with any cage closing devices. There was a possibility that some fishes, other than sandeel was trapped inside the cage along with sandeels. If so, the TS measurements can include some data coming from other species. Collected video recordings showed no other fish except the sandeels inside the cage, although some flatfishes and crabs were spotted outside the cage on several times. On the other hand, camera was observing only small area of sea bottom inside the cage, so flatfish staying close to bottom could remain unseen. Landing moment data and gained <TS> did not look like any flatfish recordings, even if such fish were present. All TS measurements from both D2L and D3L data sets contain only weak targets, while flatfish would be expected to give relatively higher TS. There is a possibility that flatfish, if present, pressed itself to the bottom and stood still when disturbed by the landing cage. Some non-sandeel, most probably flatfish was actually identified acoustically in D3 data. It happened a few times, when the reading very close to sea bottom had significantly higher TS than all the other objects seen. These readings therefore were removed from the collected TS data. Mean TS from this experiment most probably includes only sandeel TS measurements. However, acoustical data collected in deployment no.2 (namely D2 data set) was harder to check against this type of errors. Quite a lot of targets were clearly identified as sandeels (TS magnitude, across-beam-movement pattern, association with bottom), but some targets were unclear. These had relatively high TS, but not as high as the ones encountered from flatfish observed in the D3 data. Again no video recordings of non-sandeel fish were made, what supports the guess that undesirable fish TS recordings came most probably from some flatfish. In D2, <TS> is clearly and significantly higher than in all other data sets. Presence of some, maybe relatively small flatfish inside sandeel cage during experiment no.2 is therefore likely.

Considerable differences between mean TS estimates were observed. As it is seen from Fig.10 and Fig.13 mean TS estimate from D2 data is quite far away from all other estimates. During post-processing by careful TS handpicking some of the objects accepted had quite high TS, but could not be rejected as non-sandeels. Generally the entire sandeel TS distribution was expected to be below some -55dB or even lower, but when analyzing the first set of data, this was just an expectation. However, again highest TS estimates on the right tail of the distribution shown in Fig.10a may be originating from targets other than sandeel. For example in 08D TS data no measurements were made above -67dB and it was surely only sandeels present inside the cage. Furthermore, because of the TS logarithmic nature, target strength measurements in right side of distribution have higher weight in the mean of the variable than values in very left side of it. In other words doubtful and quite high TS measurements seen in right side of D2 data distribution have relatively high weight to increase the mean TS. Also must be noticed that resulting mean tilt angle from the 2007 experiment no.2 is very close to horizontal. Close to horizontal tilt angles are expected to give high target strength, but in general are not expected to be representative for individuals within schools of feeding sandeel. To summarize, the resulting <TS>=61.0dB which was estimated from D2 data set and presented in Fig.10a can be referred as “high” one and is probably affected by some sources of error that are discussed.

The remaining four mean TS estimates are much lower than first one and closer to each other. Analysis of D3 data set yielded <TS> estimate at -70.2dB. Clearly binominal distribution of TS estimates (Fig.10c) is expected to be resulting from quite small sample size, this modality may disappear with higher number of detections. Non-sandeel fish have been recognized to be present inside the cage during this experiment. Distinctive, high TS measurements were seen and filtered out. Nevertheless, the possibility that the right tail of Fig.10c TS distribution is formed by some inclusion of the readings of small flatfish can not be rejected entirely. However, D3 data was much easier to read for non-sandeel fishes than D2 and yielded mean TS is considered to be more trustful.

Mean target strength measurements from D2L and D3L were -75.2dB and -77.2dB respectively. These two data sets gave significantly lower <TS> estimates than D2 and D3, but are thought to contain many good sandeel target strength measurements. However, the data set after cage landing in deployments 2007 was a bit hard to handpick against plankton targets drifting trough the net. Some plankton detections could also be accepted as sandeel tracks. If it is true, miss-interpreted plankton TS is expected to be at middle-lower part of sandeel TS distribution. If so, calculated sandeel mean TS could be “pulled” to bit lover mode. The effect of this, however, is expected to be smaller than of accepted flatfish detections like it is probable for D2 data.

The sandeel cage experiment in 2008 was performed using sandeels captured in advance and a totally enclosed cage. There was therefore no chance for other than sandeel fish to be present inside the cage. The possibility for some miss-interpretation by plankton targets included among sandeels remained. Cage was held on a line by making the cage and echosounder transducer to move a bit up and down with sea waves. This made acoustical data harder to read and handpick, distinguish sandeel traces from plankton. Despite this, 08D is considered as a good data set and therefore yielded mean TS to be trusted. It has to be stated that mean tilt angle of the fish as measured from video data collected during this experiment is quite high positive (23.3° as mean from all individual tilt measurements) if compared with mean tilt angle gained from D2. This could partly be the reason for the higher mean TS from D2.

4.2 Comparing TS results with earlier works on sandeel

Literature on lesser sandeel target strength is still very scarce. Some experiments have been done by Armstrong and Edwards (Armstrong and Edwards, 1985; Armstrong, 1986) in mid 1980's, smaller part of data used in this thesis was analyzed by Svellingen and Ona (2007), also a work by Thomas *et al.* (2002) on related fish species can be mentioned. Target strength measurements on lesser sandeel from these papers along with results of this thesis are plotted in Fig.13.

Target strength-fish length relationship gained in this thesis is bearing b_{20} of value -99.7 ($TS=20*\log_{10}(L) - 99.7$). Expected target strength for sandeel length group seen around 2007 experiment site can be calculated: -73.6dB TS for 20.1cm sandeel. Mentioned relationship is shown as solid line in Fig.13. As it is seen from the figure, results of this work are significantly different from ones published by Armstrong and Edwards (Armstrong and Edwards, 1985; Armstrong, 1986). Sandeel TS measured in this work is lower by approximately 6dB (-73.7dB vs. -67.6dB for 20cm fish), which in terms of sandeel stock biomass estimation would increase the estimate of stock by factor of four. However, resulted TS means from six experiments performed by Armstrong and Edwards were also widely scattered: from -68.6dB down to -77.9dB for ~12-13cm sandeel at 38 kHz. Sandeel in these experiments was put inside a small cage at fairly high densities and were observed for several days at once. Large variability and cyclic nature in TS measurements was reported with quite poor discussion on possible reasons. Especially having in mind that video camera was used to observe the fish. However, burrowing behaviour (resting on cage bottom), light conditions and tidal effects were mentioned as possible explanations. Two of these three possibilities can be sources of error for high TS measurements. If sandeel was to be resting on cage bottom, very favorable tilt angles are expected to be seen. After careful examination of these two papers and results presented it looks more probable that tidal effects was accounting for cyclic pattern of measured TS size. If tidal water was streaming through in the cage, sandeels were forced to swim with tilt angles close to horizontal. Such tilt angles is not expected to be representative for freely swimming and feeding sandeels, and would give periods with high TS measurements on caged fish.

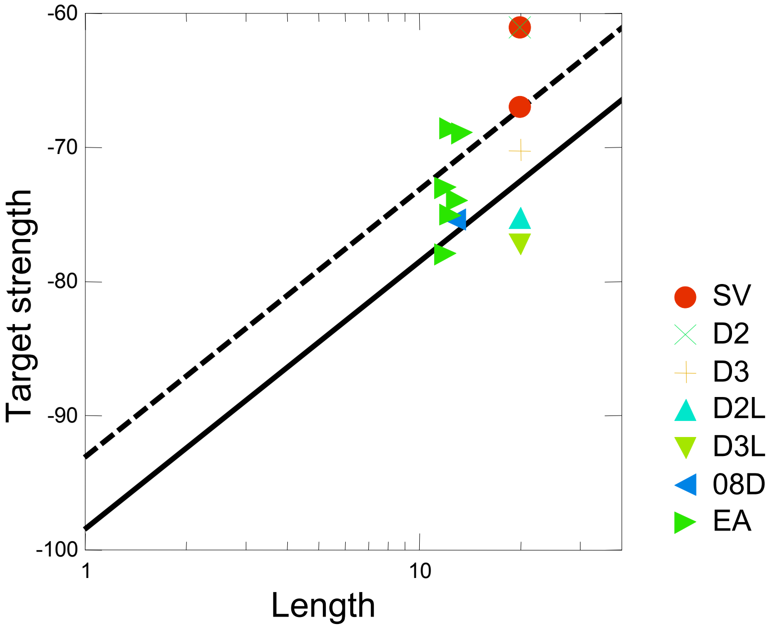


Fig.13. Sandeel target strength measurements plotted against fish length (in logarithmic scale). SV refers to measurements made by Svellingen and Ona (2007). EA are TS means from experiments made by Armstrong and Edwards at 38kHz (Armstrong and Edwards, 1985; Armstrong, 1986). D2, D3, D2L, D3L and 08D are mean TS values gained in this thesis. Solid line shows target strength-length relationship ($TS=20*\log_{10}(L) + b_{20}$) gained in this work, dashed line represents the same relationship drawn for Armstrong and Edwards data.

13 pav. Grafikas, kuriame parodyti tobio akustinio atspindžio vidutiniai matavimai. SV – matavimai gauti Svellingen ir Ona (2007). EA yra vidutiniai TS, gauti Armstrong ir Edwards (Armstrong ir Edwards, 1985; Armstrong, 1986). D2, D3, D2L, D3L ir 08D yra tobio TS vidurkiai, gauti šiame darbe. Ištisinė linija yra $TS=20*\log_{10}(L) + b_{20}$ *priklausomybė gauta iš šio darbo matavimų, punktyrinė linija – ta pati priklausomybė, gauta pagal Armstrong ir Edwards.*

The mean sandeel TS presented by Svellingen and Ona (2007) was calculated from deployment no.2 data that is used in this thesis as well. Like it was already discussed this set of data is containing quite a lot of sandeel TS measurements, but is also an object for possible error in mean TS.

In conclusion it can be said that at this stage of sandeel target strength examination experiments no “true” mean TS value can be stated. However, the range around the true value was narrowed. It seems like the true value of sandeel TS is somewhere between the two indicated regression lines drawn in Fig.13. It is also believed to be closer to lower regression line than to higher one.

4.2 Sandeel mean body tilt angle

Tilt angle measurements by using video camera were made in a slightly different way than the classical approach. Possible error sources have to be discussed. The fish tilt angle in vertical plane is important for commonly used sounders. Video or photo camera is usually placed inside the cage, aquarium or lowered inside aggregation of fish in such a way that pictures taken would have a vertical plane. Video data used in this thesis did not have a purpose of tilt angle estimations when collected. Camera was tilted and a new approach how to analyze such data had to be developed. It is described in detail in section 2.4. The important error sources are the precision of camera the tilt angle and the view opening angle estimation. However, most important to be aware of is sandeel body in-of plane position (the plane perpendicular for the photographic axis of the camera).

Camera tilt angle from a downward or an upward looking position was calculated using known measurements of sandeel cage and the position of camera. There is some uncertainty associated to the exact position of camera inside the cage. For example camera eye was not in the exact position of the cage corner pipe; the whole camera was inside the cage, just placed in the corner. It was tried to simulate camera tilt calculations by adjusting for this uncertainty in the camera position. The gained camera tilts had minor difference between each other. Furthermore, the sensitivity of fish tilt calculation for this error source was checked. It was done simply by adjusting camera tilt angle in fish tilt angle estimation equations. It appeared that even quite high ±5-6° change in camera tilt in given situations (2007 and 2008 experiments) made a difference in only ±1° of calculated fish tilt angle.

Video or photo camera is not 'looking' to one point in space, but have a view with vertical as well as horizontal extent, which can be defined in degrees. The tilt of the camera calculated to one point in the camera view opening will be valid only for fish seen in a horizontal stripe close to this point. By performing the sandeel tilt angle calculations, this source of error was accounted for. Camera tilt value was adjusted for fish seen in different parts of camera view. Again simulation by changing camera tilt values in sets of the used equations for fish tilt measurement was done. It was concluded that the error from this stage of the sandeel tilt angle estimation is very low, only ±0.2°.

The most important source of error in sandeel body tilt angle estimation is considered to be, if the fish was not perpendicular to the photographic axis. Experiments with the camera and objects simulating a sandeel have been done (see section 2.4). It was discovered that when the object or fish is in the mentioned plane the developed method for recalculating fish tilt angle form one plane to another works very well, at least with sandeel-cage camera tilts in the experiments analyzed. Tilt measurements using this technique for objects in plane parallel to the photographic axis gained estimates very close to actual one with maximum to ±0.5° error. This error can easily be caused by imperfections in the simulation experiment (e.g. camera roll left or right, object put not exactly in plane). However, it was seen that with an increasing of-plane angle error in the tilt angle estimations also increases. The error becomes undesirably high with such angles above some 20° (±4-5° in tilt estimate) and very high at angles above ±30°. Of parallel to the photographic axis plane angles at 10° gave only ±1.5-2° tilt angle miscalculations compared to the real value. Only fish images with less than 20º of-plane angles were therefore examined.

With the data quality available it was from the very beginning assumed that, estimates in some 5º interval around real sandeel tilt angle value would be a good result for this thesis. Having in mind all errors discussed above sandeel tilt angle measurements are considered to have measurement accuracy of plus minus 2-3º. This is sufficient when the tilt angle variation is high, as here.

Very large variability in sandeel tilt angles were observed and computed, which was also expected. Sandeel tilt angles were examined using pictures grabbed from two video recordings (sandeel-cage experiments in 2007 and 2008). Mean sandeel tilt angle derived by analyzing 2007 deployment no.2 video data is 1.4º as a mean per fish (m_1) and 1.8º as a mean of all single tilt angle measurements (m_2). This is very different from the 2008 video analysis results with m_1 of 13.4º and m_2 of 23.3º.

Several possible explanations for such differences could be discussed. The experiment design and environment for sandeel was different. In 2007 cage was put on the sea floor at a depth of about 40m. There were less light stimuli, also the cage was standing completely still and the bottom sediment for sandeel to hide or rest available. After examination of the video recordings it seems like most of the sandeels were swimming as single individuals in very variable directions across the camera view. Very variable tilt angles were obtained from both sets of video data with standard deviations (SD) of 24.1 for measurements around mean m_2 in 2007 and 25.4 for mean m_2 in 2008 data. Actually, with increasing tilt SD the importance of the average tilt angle for TS decreases and here, the calculated SD values is “high” according to Henderson *et al*. 2007. Most probably the sandeel tilt angle variability would decrease with higher sample size. However, 2008 experiment video recordings showed sandeel to attain to swim together with other fish and with quite similar (mostly positive) tilt angles (see appendix 2 Fig.1). Such behaviour when fish is acting in accordance with neighboring fish is typical for schools, where fish acting almost like one organism. It is not surprising, because sandeel is a schooling fish. Sandeel swimming behaviour and orientations observed in the 2008 experiment is considered to be more likely when observing freely swimming and feeding sandeel in the water column above the seabed than shown in the results from the 2007 video analysis. However, available data were very limited. The results should be treated as a pilot investigation of sandeel swimming behaviour and natural body tilt angles. Sandeel tilt angles and swimming behaviour by orientation has never been documented and measured before. The method to estimate fish tilt angle from video data of arbitrarily quality was used with an improvement introduced by author.

Sandeel tilt angle should probably not be examined by using acoustic target tracking, but rather from video or photo cameras. Sandeel not only in a cage, but also in its natural environment is expected to swim relatively slowly and its track and movement angle probably will be different from its body tilts. An interesting pattern of sandeel swimming inside the cage was observed. In both experiments, the video camera was observing only the central part of the cage, meaning that sandeels had enough of space around camera beam to swim freely and undetected. Furthermore, sandeels were spending only a few seconds inside the camera observation volume. However, a large part of the sandeels recorded on video suddenly changed their swimming direction while still being in the camera view, some of them even twice. Such unpredictable and sudden changes in swimming direction in combination with often slow swimming with high tilt angles is considered to give a possible severe error source in the tilt angle estimation, if split-beam target tracking is to be used.

There are quite few papers on fish body tilt angle examination using video or photo cameras (Olsen, 1971; Carscadden and Miller, 1980; Foote and Ona, 1987; Ona, 1984; Huse and Ona, 1996). It is an increasing number of studies on fish tilt angle using acoustics in last decade (e.g. Huse and Ona, 1996; Ona, 2001; McQuinn and Winger, 2003; Henderson *et al.* 2007). However, lesser sandeel as well as any closely related species have not been examined for body tilt angle. There is therefore no data to compare with. But some discussion can be made with regard to results on other fish species. It seems like many of the swim bladder bearing fish has close to horizontal mean tilt angle: cod (-4.4 º, SD=16.2, Olsen, 1971) capelin (3.8º, SD=18.4, Carscadden and Miller, 1980), caged saith (-0.9º, SD=5.4, Foote and Ona, 1987), herring (variable results from several studies as presented in McClatchie *et al.* 1996, also see Ona, 1984; Huse and Ona, 1996), hoki (11.8º, SD=29.9, Coombs and Cordue, 1995). These fishes have swim bladder, meaning they can adjust its position in water column not only by swimming. Swim bladder-lacking fishes, like mackerel or sandeel, are in general heavier than water, negatively buoyant and they must swim with some positive angle to keep altitude. Calculated sandeel body tilt angle from 2007 experiment is quite close to fish mean tilts given in examples. On other hand, sandeel is schooling, swim bladder-lacking, elongated, and heavier than water fish that forage on plankton and do not have to maintain a high swimming speed. Having this in mind sandeel tilt angle is more likely to be higher positive.

It can be discussed and from other point of view. Kinematics of fish locomotion requires obtaining close to horizontal tilts at high swimming speed. Close to horizontal body tilt angles are expected for fast swimming fishes or at least capable to sustain neutral buoyancy. Sandeel is negatively buoyant fish. As few most commonly discussed morphological traits of fast swimming fishes are: quite large and stiff pectoral fins, narrow necking of the caudal peduncle, fin-blades bearing and relatively big caudal fin for efficient thrust generation can be mentioned (an example: mackerel (Nauen and Lauder, 2002; He and Wardle, 2005)). Sandeel body does not have any of these traits (see appendix no.4). Furthermore, sandeel is plankton feeder strongly associated with preferred sea bottom substrate; schools of sandeel often have “connection” with sea bottom (appendix no.3), what indicates that sandeel tend to stay and forage in relatively small area. It is concluded that such traits bearing fish should be commonly observed with quite high positive mean body tilt angles. The result from the 2008 experiment with 23.3° might be a good approximation. However, more reliable estimate and further investigation is needed.

CONCLUSIONS

1. A method for obtaining fish body tilt angle from data collected using tilted camera was developed.
2. Lesser sandeel mean body tilt angle has been calculated to be 23.3º (SD=25.4). The collected data are quite limited and the results should be considered as a first attempt to investigate lesser sandeel mean tilt angle and as guidance for further studies.
3. The mean target strength of the lesser sandeel can be calculated from target strength-fish length relationship $TS=20*\log_{10}(L) - 99.7$. However, further investigation is required, for explaining the fairly low target strength obtained comparing to earlier measurements.

IŠVADOS

1. Sukurtas metodas žuvies kūno polinkio kampui vertikalioje plokštumoje matuoti, kai duomenys surinkti naudojant kamerą, kurios nuotraukų plokštuma kitokia nei vertikali.
2. Apskaičiuotas tobio vidutinis kūno polinkio kampas yra 23.3º (standartinė paklaida 25.4). Surinkti duomenys gana riboti, todėl tyrimo rezultatai turėtų būti traktuojami kaip pirmasis mėginimas ištirti tobio vidutinį kūno polinkio kampą ir atskaitos taškas tolimesniam tyrimui.
3. Vidutinis tobio akustinio atspindžio stiprumas gali būti apskaičiuotas pagal akustinio atspindžio ir žuvies kūno ilgio priklausomybe: $TS=20*\log_{10}(L) - 99.7$. Gautas vidutinis tobio akustinis atspindys yra silpnas, palyginus su ankstesniais tyrimais. Todėl reikalingas šios žuvies akustinių savybių tolesnis tyrimas.

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APPENDIX 1

Technical parameters of echosounder used in 2007 and 2008 sandeel-cage TS experiments and settings used on single target detector in LSSS are shown.

Table 1. Technical and calibration parameters of echosounder mounted on sandeel-cage.
1 lentelė. Techniniai akustinių prietaisų ir kalibracijos parametrai.

	2007	2008
Transducer type	ES-200-7CD	ES-200CD
Transmission frequency [kHz]	200	200
Transmission power [W]	300	300
Band width [kHz]	15.73	15.73
Pulse duration [ms]	128	128
Transducer angle sensitivity (along ship and athward ship)	23.0	23.0
Equivalent beam angle [dB]	-20.7	-20.7
Digital sample distance [cm]	2.4	2.4
TS Transducer Gain [dB]	-26.8	-26.8
Half power beam widths [deg]	6.95/6.94	7.00/7.00
Absorption coefficient [dB/km]	47.31	47.31
Sound speed (measured) [m/s]	1488	1488

Table 2. Single target detector (SED) settings for the target strength analysis.
2 lentelė. Atskirą objektą akustiniuose duomenyse identifikuojančio algoritmo nustatymai.

Parameter	**Settings**
Minimum TS [dB]	-95
Min/max echo length (relative to pulse length τ)	0.8τ, 1.8τ
Maximum phase deviation [el.deg.]	7.0
Maximum gain compensation [dB]	6
Min echo spacing [samples]	1

APPENDIX 2

Few pictures of sandeel that were extracted from video data. Such pictures were used by examining sandeel tilt angles.

Fig.1. Four sandeels seen in a picture grabed from 2008 sandeel-cage experiment video data.
1 pav. Viena is nuotraukų, naudotų matuojant tobio kūno polinkio kampą. Nuotrauka paimta iš 2008 metų tobio narvo eksperimento video duomenų. Nuotraukoje matyti keturios žuvys.

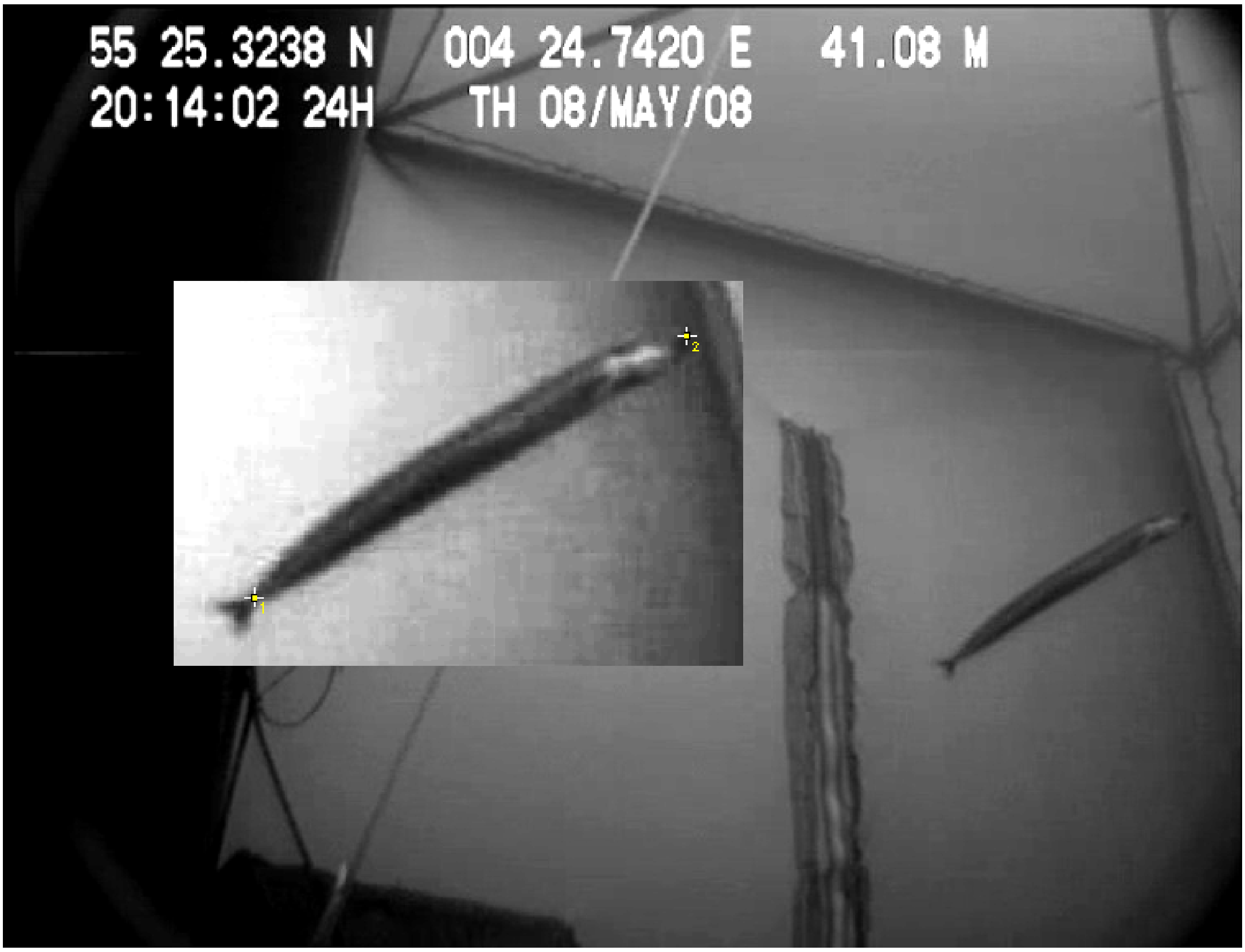

Fig.2. Picture of single sandeels with positive body tilt angle. In left side enlarged view of a fish is shown. Dots marked with numbers 1 and 2 are placed using ImageJ photo post processing software for tilt angle examination. Picture taken from 2008 sandeel-cage experiment video data.

2 pav. Tobio, plaukiančio su teigiamu kūno polinkio kampu, nuotraka. Kairėje pusėje pateiktas padidintas žuvies vaizdas su numeruotais taškais, kurių kordinatės buvo naudotos matuojant šios žuvies kūno polinkio kampą. Nuotrauka paimta iš 2008 metų tobio narvo eksperimento video duomenų.

APPENDIX 3.

Two echograms containing sandeel schools are shown. Most of the schools are associated with sea floor, have a so-called „one foot on the bottom“, what is characteristic trait of sandeel schools.

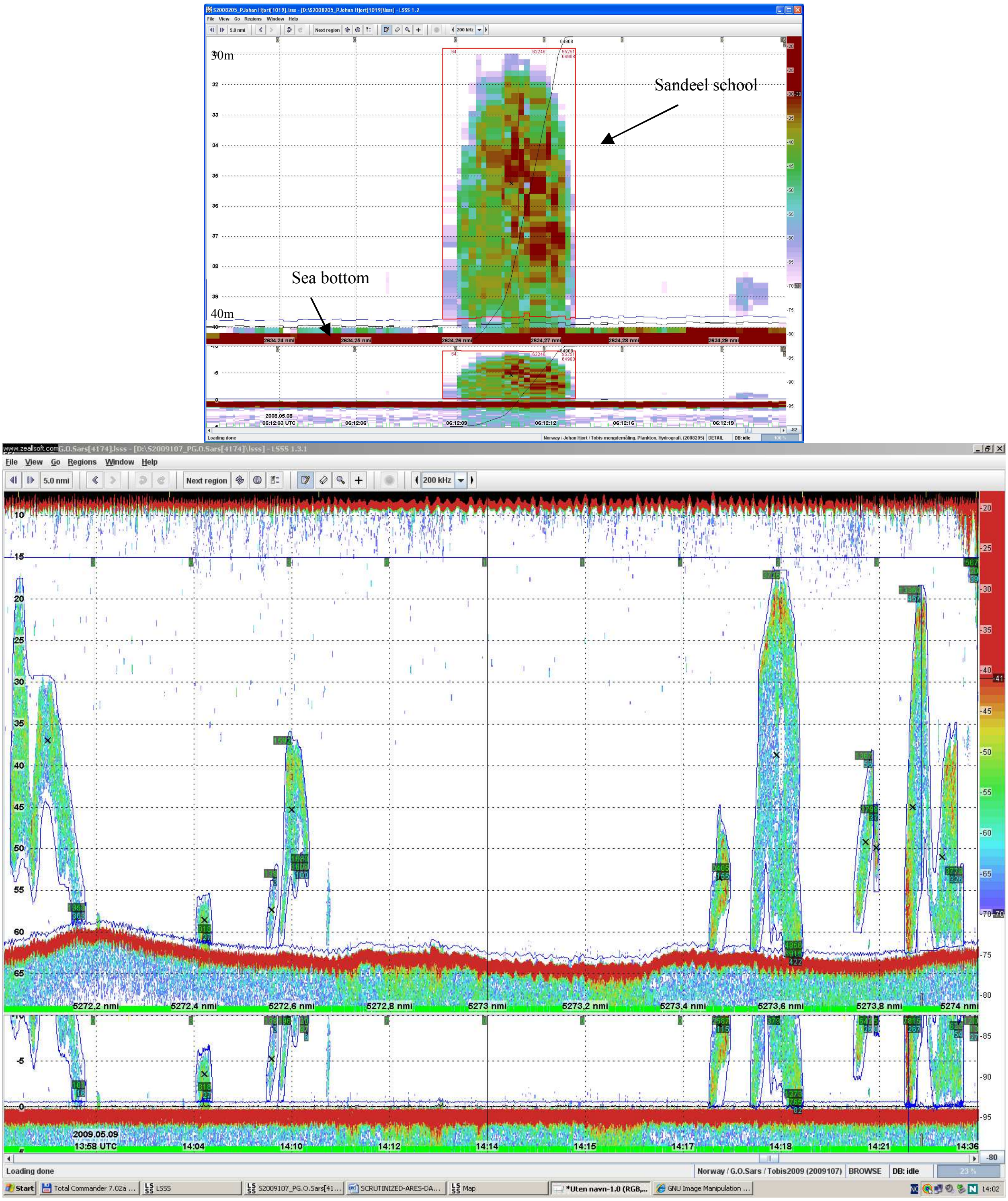

Fig.3. Top: acoustically identified sandeel school, picture at 200kHz (2007 sandeel survey data); bottom: several identified sandeel schools seen across several nautical miles in 2009 sandeel survey (RV “G.O. Sars”).

3 pav. Viršuje: akustiniais prietaisiais identifikuotas tobių būrys; apačioje: keletas tobių būrių, fiksuotų akustiniais prietaisai 2009 metų tobio monitoringo kruizo metu (mokslinių tyrimų laivas „G.O. Sars“).

APPENDIX 4.

Some aspects of lesser sandeel body morphology is shown. As it is seen in the pictures below sandeel do not have stiff and large pectoral fins, caudal fin is quite small and lacking fin-blades, necking of the caudal peduncle is relatively wide. All of these morphological traits are characteristic for slow swimming fishes.

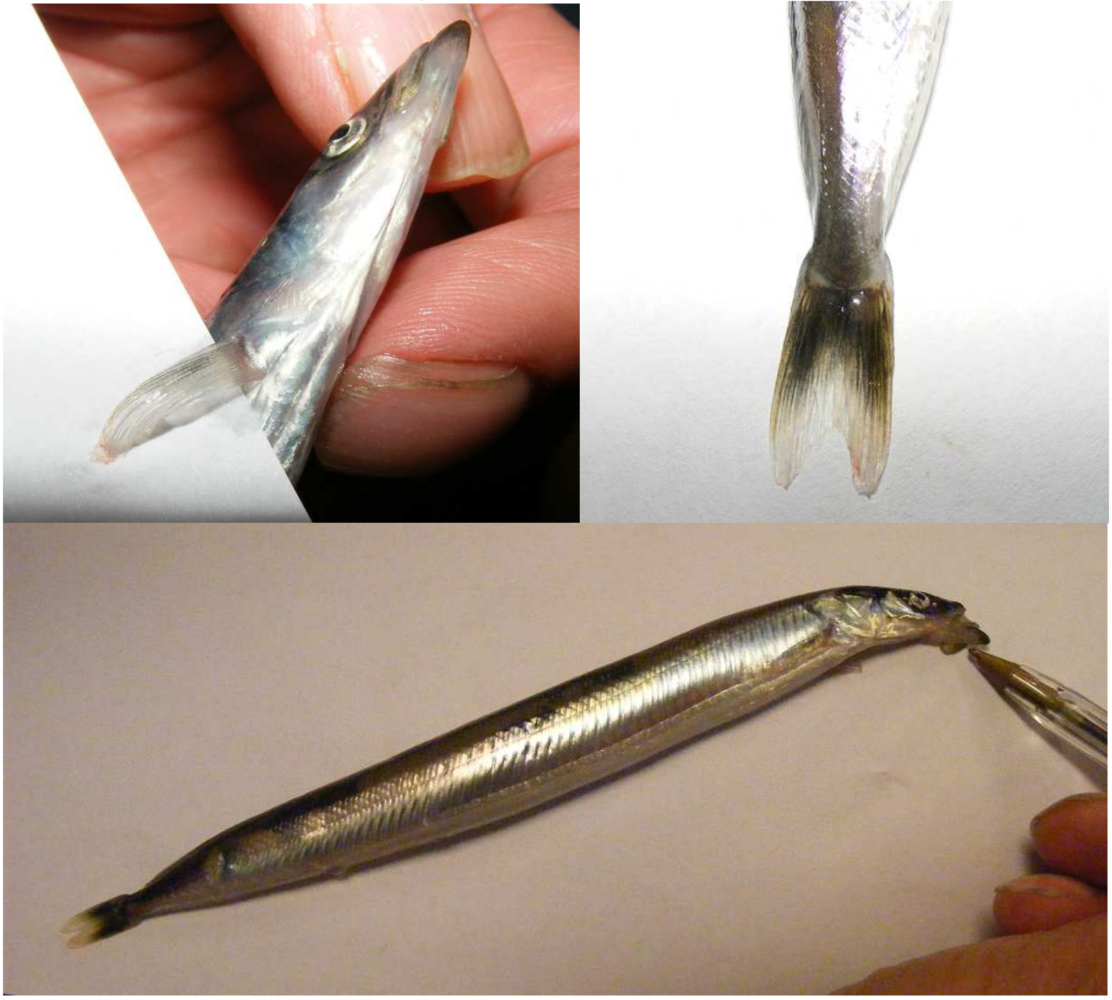

Fig.4. Sandeel pectoral and caudal fins, as well as whole fish with possible mean tilt angle of ~23.3º. Photos taken by author.

4 pav. Tobio krūtinės ir uodegos pelekai, taip pat parodytas tobis su tikėtinu ~23.3º kūno polinkio kampu.

APPENDIX 5.

Tables containing data used for drawing figures presented in this paper.

Table 3. Data used to generate a), b), c) and d) graphs in Fig.10 and graph in Fig.11. Number in brackets referes to picture number. TSC stands for beam pattern compensated target strength. -45 to -90dB interval have been taken, because TS detector on handpicking was set to accept TS detections in such interval (-45 down to -90/ -95dB).

3 lentelė. Duomenys, naudoti braižant grafikus, parodytus paveiksluose 10 ir 11. TSC reiškia „koreguotas TS, pagal akustinio spindulio formą“. Naudotas -45 to -90dB intervalas, nes detektorius skirtas identifikuoti individualius objectus buvo nustatytas priimti TS matavimus šiame intervale.

TSC averaged till integer number, dB	Number of TS measurements									
	2007.04.25 D2 (Fig.10a)		2007.04.25 D2L (Fig.10b)		2007.04.26 D3 (Fig.10c)		2007.04.26 D3L (Fig.10d)		2008.05.08 08D (Fig.11)	
	0.55-2.70m	1.10-2.70m	0.55-2.70m	1.10-2.70m	0.55-2.70m	1.10-2.70m	0.55-2.70m	1.10-2.70m	0.55-2.70m	1.10-2.70m
-45	0	0	0	0	0	0	0	0	0	0
-46	0	0	0	0	0	0	0	0	0	0
-47	0	0	0	0	0	0	0	0	0	0
-48	1	1	0	0	0	0	0	0	0	0
-49	0	0	0	0	0	0	0	0	0	0
-50	1	1	0	0	0	0	0	0	0	0
-51	1	1	0	0	0	0	0	0	0	0
-52	0	0	0	0	0	0	0	0	0	0
-53	4	4	0	0	0	0	0	0	0	0
-54	3	3	0	0	0	0	0	0	0	0
-55	1	0	0	0	0	0	0	0	0	0
-56	5	4	0	0	0	0	0	0	0	0
-57	7	3	0	0	0	0	0	0	0	0
-58	6	3	0	0	0	0	0	0	0	0
-59	4	4	0	0	0	0	0	0	0	0
-60	12	9	0	0	0	0	0	0	0	0
-61	3	3	0	0	1	1	0	0	0	0
-62	12	9	0	0	3	3	0	0	0	0
-63	7	6	0	0	1	1	0	0	0	0
-64	8	6	0	0	8	7	0	0	0	0
-65	12	10	0	0	1	1	0	0	0	0
-66	5	5	0	0	2	2	0	0	0	0
-67	8	7	0	0	1	1	0	0	2	2
-68	6	5	0	0	0	0	2	0	1	1
-69	1	1	4	4	0	0	1	0	1	1
-70	6	4	3	3	3	2	1	0	5	5
-71	4	3	7	7	3	4	3	1	1	1
-72	7	4	10	9	9	3	12	8	11	11
-73	5	4	9	9	5	1	14	8	34	32
-74	6	2	15	15	1	1	12	8	16	16
-75	6	3	15	15	25	18	8	6	23	23
-76	10	7	31	31	11	5	13	9	38	32
-77	3	2	17	16	13	19	17	8	18	16
-78	4	3	15	13	2	2	16	13	17	16
-79	3	2	36	29	4	3	98	88	16	12
-80	2	1	12	9	0	0	101	96	17	13
-81	3	4	0	0	1	1	16	9	35	34
-82	7	7	1	0	0	0	9	6	11	11
-83	2	2	0	0	0	0	5	4	6	5
-84	3	4	0	0	0	0	3	3	1	1
-85	3	3	0	0	0	0	1	1	0	0
-86	2	2	0	0	0	0	0	0	0	0
-87	0	0	0	0	0	0	0	0	0	0
-88	0	0	0	0	0	0	0	0	0	0
-89	0	0	0	0	0	0	0	0	0	0
-90	0	0	0	0	0	0	0	0	0	0

Table 4. Data used to draw graphs b) and d) in Fig.12.
4 lentelė. Duomentys, naudoti braižant b) ir d) grafikus parodytus 12 paveiksle.

2007 (Fig.12b)		2008 (Fig.12d)									
Tilt angle	Count	Tilt angle	Count								
Clumn1		*Clumn2*		*Clumn3*		*Clumn4*		*Clumn5*		*Clumn6*	
75	0	75	0	20	2	20	7	-35	0	-35	0
74	1	74	0	19	5	19	5	-36	0	-36	2
73	0	73	0	18	4	18	3	-37	0	-37	2
72	0	72	0	17	2	17	3	-38	0	-38	1
71	0	71	0	16	2	16	1	-39	0	-39	0
70	0	70	0	15	5	15	1	-40	0	-40	0
69	0	69	0	14	6	14	0	-41	0	-41	0
68	0	68	0	13	5	13	0	-42	0	-42	0
67	1	67	0	12	3	12	0	-43	0	-43	0
66	0	66	0	11	2	11	0	-44	4	-44	0
65	0	65	0	10	0	10	0	-45	1	-45	0
64	0	64	0	9	1	9	0	-46	3	-46	0
63	0	63	0	8	2	8	0	-47	0	-47	0
62	0	62	0	7	0	7	0	-48	1	-48	0
61	0	61	0	6	1	6	0	-49	0	-49	1
60	0	60	0	5	2	5	0	-50	0	-50	1
59	0	59	0	4	2	4	0	-51	0	-51	1
58	1	58	0	3	0	3	0	-52	0	-52	0
57	0	57	0	2	2	2	0	-53	0	-53	0
56	0	56	0	1	0	1	0	-54	0	-54	0
55	0	55	0	0	1	0	0	-55	0	-55	0
54	0	54	3	-1	1	-1	2	-56	0	-56	1
53	0	53	1	-2	2	-2	1	-57	0	-57	1
52	0	52	6	-3	0	-3	4	-58	0	-58	0
51	0	51	10	-4	0	-4	3	-59	0	-59	1
50	2	50	6	-5	6	-5	1	-60	0	-60	0
49	3	49	3	-6	6	-6	1				
48	1	48	4	-7	7	-7	0				
47	1	47	3	-8	3	-8	5				
46	3	46	7	-9	5	-9	1				
45	1	45	7	-10	2	-10	0				
44	0	44	5	-11	10	-11	0				
43	0	43	0	-12	5	-12	0				
42	1	42	7	-13	7	-13	0				
41	4	41	2	-14	7	-14	0				
40	0	40	2	-15	3	-15	0				
39	2	39	4	-16	6	-16	0				
38	1	38	3	-17	6	-17	0				
37	2	37	4	-18	3	-18	0				
36	3	36	3	-19	10	-19	0				
35	4	35	7	-20	10	-20	0				
34	4	34	12	-21	8	-21	0				
33	3	33	4	-22	4	-22	1				
32	1	32	14	-23	2	-23	0				
31	3	31	11	-24	1	-24	2				
30	1	30	8	-25	3	-25	0				
29	1	29	11	-26	2	-26	1				
28	2	28	8	-27	2	-27	1				
27	1	27	11	-28	1	-28	4				
26	0	26	5	-29	0	-29	5				
25	2	25	5	-30	0	-30	1				
24	2	24	3	-31	0	-31	1				
23	1	23	6	-32	0	-32	0				
22	3	22	5	-33	0	-33	2				
21	4	21	6	-34	0	-34	3				
Continued in col.3		*Continued in col.4*		*Continued in col.5*		*Continued in col.6*					

Table 5. Data used to draw graphs a) and c) in Fig12.
5 lentelė. Duonemys, naudoti braižant a) ir c) grafikus 12 paveiksle.

2007 (Fig.12a)			2008 experiment (Fig.12c)		
Fish no.	Mean tilt angle	Number of measurements	Fish no.	Mean tilt angle	Number of measurements
1	6.9	35	1	27.6	39
2	-19.8	35	2	35.5	49
3	-0.9	27	3	38.2	41
4	4.7	23	4	28.7	40
5	27.8	11	5	-7.4	8
6	52.4	9	6	-23.3	3
7	39.4	15	7	-31.4	23
8	29.3	19	8	32.4	10
9	-45.2	9	9	20.4	31
10	-10.9	35	10	45.3	9
11	-16.4	10	11	-54.0	6
12	-27.2	3	12	49.0	12
13	-22.4	5			

Table 6. Data used to draw graph shown in Fig.8.
6 lentelė. Duomentys, naudoti braižant grafiką, parodytą 8 paveiksle.

Length, cm	Number of fish		
Column1	*Column2*	*Column3*	*Column4*
10	0	21	14
11	0	21.5	9
12	0	22	12
13	0	22.5	9
14	3	23	8
14.5	3	23.5	11
15	1	24	5
15.5	1	24.5	2
16	4	25	2
16.5	4	26	0
17	5	27	0
17.5	3	28	0
18	11	29	0
18.5	7	30	0
19	27		
19.5	19		
20	22		
20.5	18		
Continued in col.3	*Continued in col.4*		

Table 7. Data used to draw graph shown in Fig.13.
7 lentelė. Duomentys, naudoti braižant grafiką, parodytą 13 paveiksle.

Source	Lenght, cm	TS, dB
D2	20.10	-61.0
D2L	20.10	-75.2
D3	20.10	-70.2
D3L	20.10	-77.2
08D	20.10	-75.4
EA (1984)	13.26	-68.9
EA (1984)	11.93	-73.0
EA (1984)	12.32	-68.6
EA (1985)	12.87	-73.9
EA (1985)	12.32	-75.4
EA (1985)	11.94	-77.9
SV	20.10	-61.0
SV	20.10	-67.0