Grant Agreement no: 817669

Acronym: MEESO

Full title: Ecologically and Economically Sustainable Mesopelagic Fisheries

H2020 project

Call: H2020-BG-2018-2020 (Blue Growth)

Topic: LC-BG-03-2018

Starting date: September 1, 2019

Duration: 48 months

D5.2

Title: Report on Initial Demographic Parameters

(Review, Sampling and Estimation of Key Demographic Parameters for Pearlside *Maurolicus muelleri* & Glacier Lantern Fish *Benthosema glaciale*)

Due date:

October 31, 2021 (Month 26)

Organization name of lead participant for this deliverable:

Danmarks Tekniske Universitet (DTU)

Dissemination level		
PU	Public	x
CO	Confidential, only for members of the consortium (incl the Commission Services)	

Deliverable number:	D.5.2
Deliverable title:	Report on Initial Demographic Parameters
Work package:	5
Lead participant:	Danmarks Tekniske Universitet (DTU)

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Keywords

Initial and key demographic and gear selectivity parameters; review, sampling and estimation; population dynamics; stock assessment; biological and ecosystem modelling; mesopelagic species; Pearlside (*Maurolicus muelleri*); Glacier Lantern Fish (*Benthosema glaciale*);

Executive Summary

The Deliverable D5.2 Report on Initial Demographic Parameters compiles information and data on key demographic parameters and gear selectivity parameters to be used to parameterize the stock assessment and biological community and ecosystem-based models and methods applied under MEESO WP5. This covers input to parameterization of i) the population dynamic and length based single stock assessment methods in the form of the TrophFishR and S6 models, ii) the StrathSPACE spatially explicit single-species models for target mesopelagic fish species, iii) the NORWECOM.E2E model for the food-web and vertical carbon flux, and iv) the SEAPODYM model for biomass and dynamics of mesopelagic functional groups.

The report presents a review of existing information on key demographic parameters from published literature as well as current outputs so far collated from MEESO. This includes outputs from the work packages (WPs) on fishing technology development with respect to e.g. gear selectivity parameters influencing length (and age) frequency sampling (MEESO WP3), and the field campaign data sampling with provision and estimation of initial biological parameters (MEESO WP4). The field campaign data also includes other research survey sampling (MEESO WP2), and sampling from commercial fishery (MEESO WP3 in cooperation with MEESO WP5). This is done in order to provide initial parameters and fitting data for the WP5 modelling tasks for the main species and stocks focused upon in the project, i.e. especially *Benthosema glaciale* and *Maurolicus muelleri*. These initial parameters will be updated later during the continued course of the field campaign and field data analyses. It should be emphasized that these parameters are initial and only very preliminary and that analyses are still ongoing on the input data from the MEESO research survey and different periods of commercial fishery sampling. Because the stock identities and delineations, as well as the migration patterns of the two species, are not fully known from the incomplete coverage of the sampling in the various existing studies, it is not known to which extent all stocks and stock

components (life stages) are covered according to the presented parameters in this report. Accordingly, the parameters should overall be used with great caution.

For example, the key requirements for the assessment models (MEESO Task 5.2, T5.2) are population length distributions obtained from surveys, technologicall or commercial trial fishery haul catches, and from acoustic survey data; estimates of the maturity ogive (proportion mature at size); weight-length relationship; and size selectivity of fishing gear. Life-history parameters (allometric exponent, energy allocation to activity and reproduction, recruitment efficiency) also required for T5.2 (and T5.3 below). The latter can also be obtained from the literature on related taxa and established life-history scaling rules. Using age-given-length data from surveys or commercial trial fisheries, natural mortality rates will be obtained from vertical life-table analysis in order to provide estimates independent of those of the purely size-based methods in T5.2. The spatial and ecosystem models in T5.3 will explore climate change scenarios which require the additional quantification of growth and/or mortality rates as functions of temperature and/or food availability. For the latter stomach content data, survey estimates of prey availability, and existing digestion rate models will be used to provide the best available estimates of feeding rate parameters of key taxa as a function of the prey field and temperature.

1.0 Literature Review on Key Demographic Parameters for Pearlside (*Maurolicus muelleri*)

1.1 Introduction

The silvery lightfish or pearlside *Maurolicus muelleri* is a small planktivorous mesopelagic fish inhabiting global oceanic waters, and largely concentrated in the temperate waters of the Atlantic and Pacific Ocean (FishBase, 2020). The lightfish is a short-lived species with a life-span of about 3 years and maximum length of 7 cm (Gjösæter, 1981). Maturity is reached after one year of juvenile life and fecundity is high (Salvanes and Sockley, 1996). *Maurolicus muelleri* feeds on copepods and euphausiids, and is itself predated on mainly by blue whiting and saithe (Gjösæter, 1981). Feeding and predatory avoidance strategies in lightfish involve diel vertical migration. The species makes use of light intensity to regulate their vertical distribution in the water column, residing closer to the surface at night and deeper in the water column during daylight (Staby et al., 2011). Its depth ranges from 50 to 400 meters, and is dependent on the ontogenetic phase of the individuals and on the time of day (Dalpadado and Gjösaeter, 1987; Staby et al., 2013). Together with the northern lanternfish *Benthosema glaciale*, the species is the most abundant mesopelagic fish in Norwegian and North Atlantic waters (Rasmussen and Giske, 1994). Following the abundances and the distribution profiles, the two fish species represent suitable and appealing targets for mesopelagic fishery activities. Due to the high body content of valuable omega-3 polyunsaturated fatty acids, the species is mainly targeted for industrial purposes involving processing the harvested resources for fish meal, oil production and nutraceuticals (Prellezo, 2019).

1.2 Review Results and Overview

Table 1.1. Parameters of life-history traits and biology of pearlside *Maurolicus muelleri* at different locations in different periods from the published literature. The outcome of the literature review shows that research has been mainly focused on North-East Atlantic waters. Additional available information on taxonomically-close species *Maurolicus stehmanni* are added for comparison.

Source	**Survey and gear**	**Space and time**	**Sampling strategy/ Depth/ Temp**	**Sample size (N)**	**Observed Standard Length (mm)**	**Von Bert. L_{inf} (mm)**	**Weight (g)**	**Von Bert. W_{inf} (g)**	**L50/ Maturity/ Fecundity**	**Sex ratio**	**Natural mortality M (y^{-1})**	**LW-relationship**	**Growth parameter k**	**Other**
Sobradillo et al., 2019	Acoustic-trawl survey with pelagic trawl	Bay of Biscay in September 2014-2017	Day (deeper) and night (shallower) Between 15 and 300 meters	283	**Min**: 26 ± 3 **Max**: 49 ± 9	-	-	-	-	-	-	-	-	-
Staby et al., 2013	Acoustic-trawl survey with pelagic trawl	Masfjorden in Nov 2007	Temperature recorded between 35 and 160 meters. Recordings from 00:00 to 12:30	-	**-**	-	-	-	**Observed min** maturity 24-30 mm	-	-	$W=0.0082*L^{3.18}$	-	Vertical migration patterns described below
Staby et al., 2011	Acoustic-trawl survey with harstad trawl	Masfjorden in Nov 2007 and Oct 2008	T=8.6 C below 90m T=14-8.5 C above 80m. Recordings between 0:00 and 14:00 between 35 and 280 m	-	**Post-larvae** 11mm **Juvenile** 21mm **Adult** 43mm	-	-	-	-	-	-	-	-	Vertical migration patterns described below

Source	Survey and gear	Space and time	Sampling strategy/ Depth/ Tempera-ture	Sample size (N)	Observed Standard Length (mm)	Von Bert. L_{inf} (mm)	Weight (g)	Von Bert. W_{inf} (g)	L50/ Maturity/ Fecundity	Sex ratio	Natural mortality M (y^{-1})	LW-relationship	Growth parameter k	Other
Kristoffensen, 2007	Biological survey with harstad trawl	Norwegian fjords and open waters in summer 1995 and 1996	-	FJ1-95: Male 63 Female 50 FJ1-96: Male 88 Female 121 FJ2-95: Male 43 FJ3-95: Male 21 FJ3-96: Male 28 Female 40 FJ4-96: Male 41 Female 78 OW-96: Male 43 Female 47	**Min**: 20 **Max**: 66	FJ1-95: Male 43.8 Female 45.0 FJ1-96: Male 44.8 Female 50.6 FJ2-95: Male 44.9 FJ3-95: Male 45.8 FJ3-96: Male 46.2 Female 51.5 FJ4-96: Male 57.2 Female 61.2 OW-96: Male 56.3 Female 56.4	-	-	-	-	-	-	FJ1-95: Male 0.88 Female 1.52 FJ1-96: Male 0.98 Female 0.63 FJ2-95: Male 1.27 FJ3-95: Male 1.47 FJ3-96: Male 1.11 Female 2.00 FJ4-96: Male 1.24 Female 1.45 OW-96: Male 1.22 Female 1.29	**t_o** FJ1-95: Male -0.02 Female 0.60 FJ1-96: Male 0.16 Female -0.57 FJ2-95: Male 0.32 FJ3-95: Male 1.11 FJ3-96: Male 0.34 Female 0.83 FJ4-96: Male 0.62 Female 0.61 OW-96: Male 0.47 Female 0.40
Kristoffensen and Salvanes, 1998	Biological survey with harstad trawl	Norwegian fjords and open waters in summer 1995 and 1996	-	OW: 314 1955 2568	OW **Mean TL**: 36.1 34.5 43.4	-	-	-	-	-	**Age based** OW Male 2.55 Female 2.00 Fjords Male 1.15 Female 0.97	-	-	-
Salvanes and Sockley, 1996	Biological survey with harstad trawl	Norwegian fjords and open waters in March-April 1995	During the day between 45 and 350 metres (upper and lower layers)	North 134 South 79 Coast 103 Fjord 170	North **Min**: 24 **Max**: 63 **Mean**: 45.2 South **Min**: 23 **Max**: 57 **Mean**: 38.9 Coast **Min** 46 **Max**: 63 **Mean**: 53.16 Fjord **Min**: 23 **Max**: 49 **Mean**: 23.95	-	North **Mean** 1.11 South **Mean** 0.81 Coast **Mean** 1.59 Fjord **Mean** 0.68	-	**Fecundity** North 16577 South 13331 Coast 36848 Fjord 16259 North & South R = 8561.14 +13.54W Coast and Fjord R=5578.18+ 13.22W	North 6:5 South 13:4 Coast 1:1 Fjord 10:59 upper 35:52 lower	-	North: $W=3.8*10^{-3}*L^{3.29}$ South: $W=4.6*10^{-3}*L^{3.23}$ Coast: $W=2.2*10^{-3}*L^{3.39}$ Fjord: $W=4.7*10^{-3}*L^{3.21}$	-	TL=2.41+1.13*SL
Goodson et al., 1995	Biological survey with harstad trawl	Herdlefjorden in Jan-Jun 1994	Between morning and evening between 70 and 270 metres depth	150 per period and age group	-	-	-	-	**Max immature** size 40 mm TL **Min mature** size 31 mm TL Maturity is reached at age-1	-	-	**Age-1:** Jan ln(FW) =-5.25 + 0.11 TL Mar ln(FW) =-4.45 + 0.085 TL May ln(FW) =-4.10 + 0.080 TL **Age-2+:** Jan ln(FW) =- 3.74 + 0.068TL Mar ln(FW) =- 3.73 + 0.069TL	**From body weight:** **Age-1**: Jan-Mar 0.008 g/g*d Mar-May 0.020 g/g*d **Age-2+**: Jan-Mar 0.004 g/g*d Mar-May 0.007 g/g*d	SL=0.17+0.85*TL

												May ln(FW) =-3.59 + 0.070TL		
Source	**Survey and gear**	**Space and time**	**Sampling strategy/ Depth/ Temperature**	**Sample size (N)**	**Observed Standard Length (mm)**	**Von Bert. L_{inf} (mm)**	**Weight (g)**	**Von Bert. W_{inf} (g)**	**L50/ Maturity/ Fecundity**	**Sex ratio**	**Natural mortality M (y^{-1})**	**LW-relationship**	**Growth parameter k**	**Other**
Rasmussen and Giske, 1994	Biological survey with harstad trawl	Masfjorden in May-June 1990	All range of 24h between 0 and 270 metres	1350	**Min** 23 **Max** 59 **Peaks** 29 and 42	-	**Min** 0.12 **Max** ~1.4	-	**Min mature** size for both sexes 29 mm SL For females 24 mm $F=0.0072*L^{3.05}$ (N=83) **Mean egg n**: 675	Size-classes 23-26: 0.27 27-29: 0.89 30-32: 1.96 33-35: 6.67 36-38: 7.25 39-41: 9.00 42-44: 14.50 45-48: 31.00	**Length based:** 0.84/y Higher in males	$W=9.0*10^{-6}*L^{3.03}$ (N=800)	-	-
Gjösæter, 1981	Biological survey with pelagic or krill trawl	Norwegian fjords and open waters during all year ~1974	-	Growth N=651 and 711 LW rel N= 97, 36 and 95	Max 70 mm Autumn age-0 16-48 mm Mean age-0 24.77 mm Mean age-1 40.33 mm	Fjords 48.8 Ocean 59.4 All combined 57.09	**Mean** 2.24	All combined 2.24	**Minimum female** SL 39 mm	-	**Age based:** 1.8	Fjords autumn $W=1.41*10^{-5}*L^{2.97}$ Fjords spring $W=6.46*10^{-5}*L^{2.42}$ Ocean spring $W=3.63*10^{-6}*L^{3.33}$ Pooled sample $W=2.04*10^{-5}*L^{2.87}$	Fjords 1.05 Ocean 0.88 All combined 0.94 **t_0** Fjords -0.21 Ocean 0.06 All combined -0.14	Annual production considering pooled sample is $P=0.23\ N_0$ g/fish; MSY= 0.17 g/recruit
Lopes, 1979	Biological planktonic and larval survey with bongo net	Masfjorden and Fensfjorden in Apr-Sep 1977	During daylight. Temperature, salinity and oxygen measured between 0 and 400 metres	-	-	-	**-**	-	-	50:50	-	-	-	**Egg abundances** Masfjorden $9*10^{10}$ eggs Fensfjorden $56*10^{10}$ **SSB**=E/F *S*W Masfjorden $6.6*10^{9}$ tons Fensfjorden $30,7*10^{9}$
Fish base (with no references)	-	-	-	-	**Max** 80 mm TL **Mean** 40 mm TL	-	-	-	F=200-500	-	-	$W=4.6*10^{-3}*TL^{3.16}$ Range for a= 0.00197 - 0.01063 Range for b= 2.95 - 3.37	0.88	Trophic level=3±0
Young et al., 1987	Biological survey with pelagic trawl	Tasmania from Apr 1984 to Jun 1985	Temperature and sampling recorded around 200m. Mean T_{200} 11.6-13.5C	141	**Min** 34 **Max** 54 Length-distr available divided in size classes, sex and months	-	-	-	Observed mature female 38-53 mm Observed mature male 34-46 mm	2.64:1	-	-	-	-

Source	Survey and gear	Space and time	Sampling strategy/ Depth/ Temperature	Sample size (N)	Observed Standard Length (mm)	Von Bert. L_{inf} (mm)	Weight (g)	Von Bert. W_{inf} (g)	L50/ Maturity/ Fecundity	Sex ratio	Natural mortality M (y^{-1})	LW-relationship	Growth parameter k	Other
Battaglia et al 2010	----	Strait of Messina, central Mediterranean sea. 2007-2009	Samples collected before the sunrise.	93	SL: 12.00-50.0 TW: 0.02-2.10 gr.									
Dalpadado and Gjøsaeter, 1987	Acoustic-trawl survey with pelagic or krill trawl	Red Sea in March 1981	During the 24h mainly a night between 20 and 350. T=22C at 220-280m	82	Female range 20-40 mm Male range 14-34 mm **Max** 40 mm	-	-	-	**Min** Female 20 Male 19 logF=2.657*log(L-1.545)		-	-	-	-
Clarke, 1982	Biological survey with pelagic trawl	NSW and Tasmania ~1977	Between 50 and 400 metres	-	**Min** 23 **Max** 50 Size-age **groups**: 23-39 mm (39-40 at age-1) 43-50 mm (45-50 at age-2)	-	-	-	F=-788+25.7*SL		-	-	-	-
Prosch, 1991	Biological survey with bongo net and commercial samples	Benguela ecosystem monthly from Aug 1977 to Aug 1978	T=13-15C at 40 metres along the year	-	**Max** 53 mm	-	-	-	**Min** observed Female 26 mm SL Male 24 mm SL	1.2:1	-	-	-	Fecundity of mean 334 eggs/g (161-738 eggs/g)
Boehrlet et al 1994														
Ikeda, 1996	Biological survey with mid-water-trawl net and larvae nets	Japan Sea in 1988-1992	At night	312	**Min** 3.6 mm TL **Max** 53.0 mm TL **Mean** 36.0 mm TL	**TL_{inf}**=59.5 mm	**Min** 0.15 **Max** 1.238	-	-	-	-	Allometric $W=0.00211*TL^{3.346}$	1.19 (t_0=0.65)	Life span of 1.8 years (20-22 months)
Bellucco et al., 2004	Acoustic-trawl survey with Mid-water-trawl net	Brazil in Jul 1996-Dec 1997	-	-	-	**L_{inf}**=53-55 mm	-	-	-		-	-	0.0097-0.0088 d^{-1}	t_0=8.03-5.5 d
Almeida and Rossi-Wongtschowski, 2007	Acoustic-trawl survey with Mid-water-trawl net	Brazil in Jul 1996-Dec 1997	-	6132	**Min** 12 mm **Max** 52 mm	**L_{inf}**=53 mm	-	-	**L50**=32mm **Min** observed Female 24 mm Male 23 mm	1:1	-	$W=2.0*10^{-5}*L^{2.89}$	-	-

Maurolicus muelleri in NE Atlantic/Norway

Maurolicus muelleri in other regions

Maurolicus stehmanni

1.3 Additional relevant information available in the above-mentioned literature

Sobradillo et al., 2019 → A vertical distribution profile is available. No length-frequency distribution graph displayed.

Kristoffensen, 2007 → Temperature was recorded at sampling depth but not shown in a table. Temperature was about 1 degree lower in the open waters compared to the fjords environment.

Kristoffensen and Salvanes, 1998 → Temperature was recorded at sampling depth but not shown in a table. The temperature regime experienced by the fish is different in the open sea than in the fjords. In the fjords, the temperature at different water layers is stable and similar in values from one fjord to another. The open waters have a warmer upper layer and a colder deeper layer. Mean instantaneous mortality rate (Z) was estimated from the slope of the catch curve over age classes (4-5 classes used). Assumptions include: constant rate of mortality, no recruitment variation and no gear selection. Abundances of fish were found to decline with latitude. There are three location-specific length distribution graphs available.

Salvanes and Sockley, 1996 → *Maurolicus muelleri* is described as a rapidly maturating species which lives a short life of up to about 3 years. The Age-1+ group locates in the upper part of the SSL while age-2+ locates in the lower part of the layer. There is a length-frequency distribution graph available for each of the four areas.

Goodson et al., 1995 → There are length-frequency distributions graphically available in the paper, distinguished for January, March, May and June. The graphs show the gradual overlapping of year-classes in the water column distribution (neatly separated upper and lower layers), with juvenile age-0 merging the adult population in the SSL when approaching summer. Growth rate was higher in January than in June, thus the size differences between juvenile and adults decreased towards summer. The vertical distribution is characterized by ascent at dusk and descent at dawn. Seasonality (strong at such high latitude) strongly influences the species' behaviour. The pattern of vertical migration also shifts seasonally, depending on whether survivorship, in winter, or reproduction, in summer, is the predominant motivation.

Rasmussen and Giske, 1994 → The annual mortality rate between age-1 and age-2+ was calculated from the length-frequency distribution assuming equal year-class strength. It should therefore be considered with caution. The age classes identified go from 0 to 3+, and with some individuals potentially of age-4. A plot of length-frequency distribution is available in the paper. In May, the vertical distribution profile consists of: max depth of SSL between 11:00 and 15:00 in the afternoon (lowest depth at 14:15 pm); min depth of SSL between 23:30 and 3:30 at night. Stomach content analysis available. During the summer, the fish locate between 120 and 170 metres during the day, while between 0 and 30 metres at night. In winter, juvenile stays between 70 and 100 metres during the day but the adults locate 50 metres deeper in the lower layer.

Gjösæter, 1981 → The mortality is calculated from length-distribution over age classes (I-IV) through geometric mean regression, but they underline a gear selection bias. High mortality between 2-3 years old individuals is highlighted in the summer. Growth was found higher in the fjords compared to the open ocean, and the L_{inf} value seemed lower in the fjords. Production per year is estimated to be 0.23 g/fish. The method used assumes that the mortality is constant. In reality, the natural mortality seems to be low during the first part of life when production is high, and higher during older ages, when growth, and therefore production, is very slow. These effects will tend to make P = 0.23 g an underestimate. Further stomach analyses are available in the paper. The maximum sustainable yield was calculated to occur at a fishing mortality of between 5 and 6, with an age of 0.6 years at first capture. Age at recruitment is considered to be 0.25 and max age is 3.5 years.

Giske and Aksnes, 1992 → This paper is not included in the table above but contains information on feeding rate, growth rate, and parameters, but not in terms that correspond to those of the table.

Young et al., 1987 → The temperature profile at 200m is available in graphic form. Two tables with sex-grouped frequencies for each SL class are available in the paper. The sex ratio was consistent among size classes with females always outnumbering males. The spawning season is prolonged from August to October. Different eggs development coexisted in time underlying a batch spawning behavior.

Dalpadado and Gjøsaeter, 1987 → This paper includes scarce information on the zooplankton community and diet. The fish locate between 350 and 450 during the day but some schools of *Maurolicus* were observed between 50 and 200 during the day. A table with sex-grouped frequencies for each SL class is available in the paper.

Clarke, 1982 → A graphical representation of the size-classes harvested along the depth profile is available. Length-frequencies (not good for extraction but only for visualization) among the sampling months is available.

Prosch, 1991 → Spawning in the Benguela area peaks in spring/early summer. Yearly temperature profile at 40 metres available, with further references in the text to other studies which determine hatching temperatures and spawning preferences.

Melo and Armstrong, 1991 → This paper is not included in the above table, but it contains some information about fecundity of *Maurolicus muelleri* in the Benguela ecosystem in 1989. Fecundity was calculated over standard length and resulted in the equation $y=3.52x + 41.14$. Mean relative fecundity was found to be 203 eggs/g (ovary-free fish) or 182 eggs/g (whole fish).

Almeida and Rossi-Wongtschowski, 2007 → A table of size-classes frequency distribution is available. No significant sex ratio different from 1:1 was found overall. Description of the use of $L50/L_{inf}$ ratio information and its approximation to L_{min}(obs. at maturity)/L_{max}(observed).

Staby et al., 2013 → Three SSLs are identifiable by the echogram. SSL1 is situated at 50-60 metres and is composed of post-larvae, SSL2 is situated at 66-80 metres and is composed of juveniles, and SSL3 is at 110-165 metres and composed of adults. SSL1 and SSL2 displayed ascent towards the surface, reaching it at sunset, and descent towards their usual depth, reaching it before sunrise. The SSL3 layer mainly remained at constant depth. The mortality over feeding rate ratio is smaller for post-larvae than for juveniles and adults. This is because at higher light intensity the larvae feed at higher rate, and consequently grow at higher rates, and experience a smaller mortality rate for their reduced dimensions (less susceptible to visual predation). Instead in deeper layers and larger individuals still have a high feeding rate but also the predation rate by visualization increases.

Staby et al., 2011 → Length-frequency distributions are available in the paper, separated by day and night, for SSL and for two years. Temperature and salinity profiles are also available. Catches in kg are available for each trawl sample. The observed vertical distributions consisted of 3 layers in 2007: two at 50-75m and one at 115-175m during daytime. In 2008 the layers were 3 neatly separated in 70-90 m, 110-125m and 155-215 m. Above 200m the catches were dominated in biomass by *Maurolicus*. Monthly-based 24h-echograms are available.

1.4 References for Pearlside

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2.0 Literature Review on Key Demographic Parameters for Glacier Lantern Fish (*Benthosema glaciale*)

2.1 Introduction

The glacier lantern fish or *Benthosema glaciale* is a small planktivorous, non-migratory mesopelagic fish inhabiting Atlantic oceanic waters, mainly concentrating in the northern Atlantic Ocean (FishBase, 2020). The species has a wide temperature tolerance and is mainly present in waters with temperatures between 4-16°C. The geographical distribution limits in the southern Atlantic and in the Eastern Mediterranean correspond closely to the 15°C isotherm of average annual temperature at 200 m (Gjösæter, 1973; Schroeder, 1963). The glacier lantern fish is a short-living species with a maximum life span of about 8 years (Muus & Nielsen 1999), a small body size with a maximum length of 10.3 cm (Hulley, 1990), a high growth rate and a small size at maturation (García-Seoane et al., 2014). During the winter season however, growth in body length slows or nearly ceases (Kawaguchi & Mauchline, 1982). Maturation is reached at the age of 2 or occasionally 3 years (Gjøsæter, 1981).

Benthosema glaciale feeds mainly on Copepods (Kawaguchi & Mauchline, 1982). Distinct vertical migrations occur with high abundances at lower depths (150-530 m) during the day and closer to the surface during the night (45-90 m) to feed on zooplankton (Halliday, 1970). The glacier lantern fish is mainly predated on by gadoid fish, such as saithe and blue whiting (Dypvik & Kaartvedt, 2012). The diel vertical migration is a trade-off between feeding opportunities and predation risk, with light being the trigger mechanism (Dypvik & Kaartvedt, 2012; Pearre, 2003). Together with the northern pearlside *Maurolicus muelleri*, the species is the most abundant mesopelagic fish in Norwegian and North Atlantic waters and together they are therefore the most attractive targets for mesopelagic fishery activities (Rasmussen & Giske, 1994).

2.2 Review Results and Overview

Table 2.1. Parameters of life-history traits and biology of glacier lantern fish or *Benthosema glaciale* at different locations in different periods from the published literature. The outcome of the literature review shows that research has been mainly focused on North-East Atlantic and North-West Atlantic waters.

Source	Survey and gear	Space and time	Sampling strategy/ Depth/ Temp	Sample size (N)	Observed Standard Length (mm)	Von Bert. L_{inf} (mm)	Weight (g)	Von Bert. W_{inf} (g)	L50/ Maturity/ Fecundity (mm)	Sex ratio	Natural mortality M (y^{-1})	LW-relationship	Growth parameter k	Other
Halliday 1970	6-ft Isaacs-Kidd midwater trawl without closing devices	Central Nova Scotia, Between May 1967 and January 1969	Day (less than 8.5 C and most between 5-6 C) depths below 250 fath and night (most between 4-9.5 C) Depths from 25 – 50 fath	4350	Range: 10-70	68.28			37 Age: 2-3				0.36	t_0 : 0.49
Gjøsæter 1973	Isaacs-Kidd three-foot midwater trawl And a Beyer low speed midwater trawl	fjord system in the Bergen area of the west coast of Norway 1969	100-400 m 7.0 - 8.2 °C	644	Range: 37-71	75				54.8	58%		0.45	t_0 : 0.25
Gjøsæter 1981	Pelagic fish trawl & Isaacs-Kidd midwater trawl	Norway 1973-75		1111	57.7 Range: 48-75	70-87 All samples: 83.063		8.68	45-50 Age 2-3 years 700 eggs/female relation between fecundity (F) and body length (L): LOG F = -3.21 + 3.44 log L (r2 = 0.866)	54.8%	0.7	Off the coast: $W = 7.6*10^{-7} l^{3.66}$ Spring-summer: $W = 8.4*10^{-6} l^{3.10}$ Autumn: $W = 2.8*10^{-6} l^{3.41}$ the total fjord material: $W = 4.8*10^{-6} l^{3.26}$ (weight in gram and length in mm)	0.19-0.46 All samples: 0.204	Batch fecundity: 781 (n: 28) Spawns mainly during summer All samples: t_0 : -0.64

Source	Survey and gear	Space and time	Sampling strategy/ Depth/ Temp	Sample size (N)	Observed Standard Length (mm)	Von Bert. L_{inf} (mm)	Weight (g)	Von Bert. W_{inf} (g)	L50/ Maturity/Fecundity (mm)	Sex ratio	Natural mortality M (y^{-1})	LW-relationship	Growth parameter k	Other
Kawaguchi and Mauchlinea (1982)	Pelagic trawling	southern part of the Rockall Trough off northwestern Ireland	Depths from 630-2,700 m		40 ± 7.1 Range: 32-55				30 – 39 mm 2 years	53 %				Batch fecundity: 357 ± 153 (n: 8)
Mazhirina, 1988		Hatton Plateau							33-35					
Kristoffersen & Salvanes (2009)	pelagic Harstadtrawl and Aakratrawl	Norway 1993-1997	>300m											
Kristoffersen & Salvanes (2009)		Herdlefjorden		214		70.4					1.03		0.45	t_0 : 0.03
Kristoffersen & Salvanes (2009)		Masfjorden		169		69.7					0.99		0.60	t_0 : 0.22
Kristoffersen & Salvanes (2009)		Sognefjorden		151		64.8					1.50		0.38	t_0 : -1.13
Kristoffersen & Salvanes (2009)		Norwegian Sea		173		106.2					1.04		0.18	t_0 : -0.26
Garciá-Seoane et al., 2014	pelagic and bottom trawl gear	Flemish Cap from a) 18 June to 22 July 2008 and b) from 21 June to 22 July 2010	a) 0-300m b) 300-650m	Total 1213: 551 males, 549 females and 113 individuals of indeterminate sex a) 132: 66 males, 46 females b) 1081: 485 males, 503 females	Total: 52 ±10, 54 ±10 (M), 53 ± 9 (F) a) 54 ±10: 57 ± 7 (M), 56 ± 8 (F) b) 52 ±10: 53 ±10 (M), 53 ±10 (F) **Range:** **a) Min: 28** **Max: 71** **Males & females: 40-71** **b) Min: 28** **Max:81** **Males: 32-73** **Females: 31-81**	Total: 69.546, 69.896 (M), 69.8665 (F) a) 70.073: 70.870 (M), 69.463 (F) b) 69.809: 70.480 (M), 70.165 (F)	-	-	47.6	a) 1:2.66 b) 1:1	Overall population: 0.65 age1: 1.09 age2: 0.79 age3: 0.60 age4: 0.49 age5: 0.44 age6: 0.39	-	Total: 0.471, 0.468 (M), 0.463 (F) a) 0.428: 0.414 (M), 0.443 (F) b) 0.471: 0.463 (M), 0.461	t_0 : -0.403
Garciá-Seoane et al., 2015	(1) a) two types of gear for pelagic and bottom fishing in 2009. Pelagic fishing: Isaacs-Kidd Midwater Trawl of 4 m2. Bottom fishing: Lofoten type trawl b) bottom trawl in 2011.	(1) the Flemish Cap (Northwest Atlantic) in a) early summer June–July 2009 and b) June–August 2011	(1) 0 - 600 m	(1) a) 142 b) 43	33.9 ± 3.6 Range: 27-43				(1) a) 47.6 b) 49.1					Batch fecundity: 491 ± 228 (n: 33)

Source	Survey and gear	Space and time	Sampling strategy/ Depth/ Temp	Sample size (N)	Observed Standard Length (mm)	Von Bert. L_{inf} (mm)	Weight (g)	Von Bert. W_{inf} (g)	L50/ Maturity/Fecundity (mm)	Sex ratio	Natural mortality M (y^{-1})	LW-relationship	Growth parameter k	Other
Garciá-Seoane et al., 2015	(2) two types of gear for pelagic and bottom fishing Pelagic: double-warp-modified commercial mid-water trawl bottom fishing: Isaacs-Kidd Midwater Trawl of 3 m2	(2) off the Balearic Islands (western Mediterranean) in a) late autumn (December) 2009 and b) early summer (July) 2010	(2) 200 m and 600-900m	(2) a) 72	Range: 27-43				(2) a) 24.5					Batch fecundity: 491 ± 228 (n: 33)
Haliday et al., 2015	International Young Gadoid Pelagic Trawl (IYGPT)	Central Nova Scotia, 1984–89			Night Range: 13-71 Median: 25 Day Range: 18–79 Median: 31				32–33 in WSW (Warm Slope Water) 39-40 in LSW (Labrador Slope Water)					
Tåning 1918		Mediterranean Sea			36 ± 3.1 Range: 32-40				30					Batch fecundity: 323 ± 94 (n: 6)

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3.0 Key Demographic (Biological) Parameters for Pearlside (*Maurolicus muelleri*) and Glacier Lantern Fish (*Benthosema glaciale*) Collated and Estimated from MEESO Survey Sampling (Work Packages 4 & 2 & 5)

3.1 Introduction

This section contains the initial parameters obtained so far from outputs on the field campaign data sampling with provision and estimation of initial biological parameters under the survey sampling associated to the MEESO project (MEESO WP4 & WP2 & WP5). It should be emphasized that these parameters are initial and only very preliminary, and that analyses are still ongoing on the input data from the MEESO research survey sampling. Accordingly, the parameters should be used with great caution.

3.2 Initial Results and Overview from Research Survey Sampling

Table 3.1. Parameters of life-history traits and biology of pearlside (*Maurolicus muelleri*) and glacier lantern fish (*Benthosema glaciale*) obtained at different locations and in different periods from the MEESO research survey sampling.

Source & Species	**Survey and gear incl. selection parameters**	**Space and time**	**Sampling strategy/ Depth/ Temp**	**Sample size (N)**	**Observed Standard Length (mm)**	**Von Bert. L_{inf} (mm)**	**Weight (g)**	**Von Bert. W_{inf} (g)**	**L50/ Maturity/Fecundity (1)**	**Sex ratio F:M**	**Natural mortality M (y^{-1})**	**LW-relationship TW vs SL**	**Growth parameter k**	**Other IGS(±SD)(2)**
AZTI survey 2019 Maurolicus muelleri	Acoustic-trawl survey with pelagic trawl Hampidjan Gloria 352. Vertical opening 15 m Gradual mesh codend, with 13.5 mm, 9 mm and 5 mm mesh sizes. Trawls: Apollo Poly-Ice 3.0 m2.	Bay of Biscay September	Opportunistic survey Between 15 and 400 metres Temp (3m): 14.7-22.6 °C Temp (50m): 11.7-16.8 °C	100 individual per haul 400 analyzed	18-51		0.06-1.71		Females L50:35.77 Males L50: 36.10 Fecundity 394±156 eggs/g (Whole fish)	The sex ratio presented significant differences with SL 0.56:0.44		a= $7.08*10^{-6}$ b= 3.10		Age 0 to 1 IGS (%) = 2.01±1.59
AZTI survey 2020 Maurolicus muelleri	Acoustic-trawl survey with pelagic trawl. Idem AZTI survey 2019	Bay of Biscay September	Opportunistic survey Between 15 and 400 metres Temp (3m): 17.2-24.0°C Temp (50m): 12.0-16.9 °C	100 individual per haul 500 analyzed	18-55		0.07-1.96					a =$1.08*10^{-5}$ b= 3.03		Age 0 to 1 IGS (%) = 4.54±1.84
Historical JUVEN serires 2013-2020 Maurolicus muelleri	Acoustic-trawl survey with pelagic trawl. Idem AZTI survey 2019	Bay of Biscay September	Opportunistic survey Between 15 and 400 metres	100 individual per haul	1.5-6.5 **cm Total length**									Distribution by cm from 2013 to 2017 and by half cm onwards
Biological samples from MEGS suvey Maurolicus muelleri	pelagic trawl. Idem AZTI survey 2019	Bay of Biscay April	Opportunistic survey T50m= 12.6ºC	62 individuals analyzed	37-53		0.55-1.94					a =$2.19*10^{-5}$ b= 2.82		Age 2 IGS (%) = 5.58±2.33
Biological samples from BIOMAN 2020 suvey Maurolicus muelleri	pelagic trawl. Idem AZTI survey 2019	Bay of Biscay May	Opportunistic survey T50m= 12.7ºC	138 individuals analyzed	29-51		0.39-1.79					a =$4.64*10^{-5}$ b= 2.66		Age 1 to 2 IGS (%) = 7.48±2.63

Source & Species	Survey and gear incl. selection parameters	Space and time	Sampling strategy/ Depth/ Temp	Sample size (N)	Observed Standard Length (mm)	Von Bert. L_{inf} (mm)	Weight (g)	Von Bert. W_{inf} (g)	L50/ Maturity/Fecundity (1)	Sex ratio F:M	Natural mortality M (y^{-1})	LW-relationship TW vs SL	Growth parameter k	Other IGS(±SD)(2)
Biological samples from BIOMAN 2021 suvey Maurolicus muelleri	pelagic trawl. Idem AZTI survey 2019	Bay of Biscay May	Opportunistic survey 10-234 metres TSup= 15ºC	100 individuals analyzed	40-58		0.64-2.42			37% Males 63% Females		a =6.52*10^{-6} b= 3.16		Age 1 to 2 IGS (%) = 7.5±3.14
Biological samples from WESPAS 2020 survey Maurolicus muelleri AZTI measurements	pelagic midwater trawl 85 m length, fishing circle 420 m, wing mesh size 2.4 m graded through to codend 10 cm	Celtic sea June 1 haul 50.41ºN-11.18ºW	Opportunistic survey 121 metres Temp: ~10ºC (below thermocline (35-50m)	138 individuals analyzed	40-61		0.72-1.77			26% undef 34% Males 40% Females		a =1.21*10^{-5} b= 2.99		Age 2 IGS (%) = 7.31±3.47
Biological samples from WESPAS 2020 survey Maurolicus muelleri On-board measurements	pelagic midwater trawl 85 m length, fishing circle 420 m, wing mesh size 2.4 m graded through to codend 10 cm	Celtic sea June Haul 10; 50.41ºN-11.18ºW	Opportunistic survey 121 metres Temp: ~10ºC (below thermocline (35-50m)	100 individuals length/weight	Total length range 49-67, mean = 56.22		range 0.6-2.0 mean = 1.23							
Biological samples from WESPAS 2021 survey Maurolicus muelleri On-board measurements	pelagic midwater trawl 85 m length, fishing circle 420 m, wing mesh size 2.4 m graded through to codend 10 cm	Haul 23; 50.68 ºN-11.31 ºW	Opportunistic survey	100 individuals length/weight	Total length range 52-70, mean = 61.06		range 0.8-1.7 mean = 1.25							
Biological samples from WESPAS 2021 survey Maurolicus muelleri On-board measurements	pelagic midwater trawl 85 m length, fishing circle 420 m, wing mesh size 2.4 m graded through to codend 60 mm	Haul 27; 51.12 ºN-11.63 ºW	Opportunistic survey	13 individuals for length/weight	Total length range 52-63, mean = 59.61		range 0.7-1.5 mean = 1.15							
Biological samples from IBWSS 2021 Survey Maurolicus muelleri AZTI measurements	pelagic trawl 82 m length, fishing circle 768 m, wing mesh size 12.8 m graded through to codend 60 mm	West of Ireland April Haul 13: 59.85ºN-13.31ºW	Opportunistic survey 220 metres Temp (50m): ~9ºC	94 individuals analyzed	27-63		0.14-1.30			95% undef 3% Males 2% Females		a =9.70*10^{-6} b= 2.99		Age 1 IGS (%) = 6.36±4.13

Source & Species	Survey and gear incl. selection parameters	Space and time	Sampling strategy/ Depth/ Temp	Sample size (N)	Observed Standard Length (mm)	Von Bert. L_{inf} (mm)	Weight (g)	Von Bert. W_{inf} (g)	L50/ Maturity/Fecundity (1)	Sex ratio F:M	Natural mortality M (y^{-1})	LW-relationship TW vs SL	Growth parameter k	Other IGS(±SD)$^{(2)}$
Biological samples from IBWSS 2021 Survey Maurolicus muelleri On-board measurements	macroplankton trawl 92 m fishing circle, non-graded 8 mm stretched mesh	Haul 10; 58.53ºN-9.02ºW	Opportunistic survey	308 individuals	Total length range 21-49, mean = 29.03		mean = 0.14*							
Biological samples from IBWSS 2021 Survey Maurolicus muelleri On-board measurements	macroplankton trawl 92 m fishing circle, non-graded 8 mm stretched mesh	Haul 12; 59.85ºN-13.32ºW	Opportunistic survey	389 individuals	Total length range 20-43, mean = 27.99		mean = 0.13*							
Biological samples from IBWSS 2021 Survey Maurolicus muelleri On-board measurements	pelagic trawl 82 m length, fishing circle 768 m, wing mesh size 12.8 m graded through to codend 60 mm	Haul 13; 59.85ºN-13.31ºW	Opportunistic survey	100 individuals	Total Length range 22.4-68.9, mean = 45.15		range 0.2-2.4, mean = 0.68							
Biological samples from IBWSS 2021 Survey Maurolicus muelleri On-board measurements	pelagic trawl 82 m length, fishing circle 768 m, wing mesh size 12.8 m graded through to codend 60 mm	Haul 14; 60.22ºN-7.92ºW	Opportunistic survey	108 individuals	Total Length range 29-69, mean = 42.47		mean = 0.57*							
Biological samples from SINTEF 2019 Survey Maurolicus muelleri	pelagic trawl	Norwegian waters November	Commercial survey Between 120-175m	199 individuals analyzed	30-68		0.13-2.14			89% undef 4.5% Males 6.5% Females		a =4.45*10^{-6} b= 3.24		Age 0 to 3 IGS (%) = 1.09±0.86
Biological samples from IMR 2020 survey *Maurolicus muelleri*	pelagic trawl	Norwegian waters March	Scientific survey 230 meters	76 individuals analyzed	40-75		0.38-3.22			70% undef 13% Males 17% Females		a =9.25*10^{-6} b= 3.12		Age 1 to 4? (1 individual) IGS (%) = 5.81±2.87
Catch length distributions from IMR cruise 2016115	Non-graded trawls	Norwegian Sea and Norwegian fjords	Scientific survey	24 trawls/904 individuals	11-56									

Source & Species	Survey and gear incl. selection parameters	Space and time	Sampling strategy/ Depth/ Temp	Sample size (N)	Observed Standard Length (mm)	Von Bert. L_{inf} (mm)	Weight (g)	Von Bert. W_{inf} (g)	L50/ Maturity/Fecundity (1)	Sex ratio F:M	Natural mortality M (y^{-1})	LW-relationship TW vs SL	Growth parameter k	Other IGS(±SD)$^{(2)}$
Catch length distributions from IMR cruise 2018106	Non-graded trawls	North Atlantic including Norwegian fjords	Scientific survey	25 trawls/1203 individuals	27-59									
Catch length distributions from IMR cruise 2019703	Non-graded trawl, 8 mm stretched mesh size	Cape Verde to Bay of Biscay	Scientific survey	4 trawls/125 individuals	11-52									
Catch length distributions from IMR cruise 2013107	Non-graded trawl, 8 mm stretched mesh size	Norwegian Sea, Iceland Sea, Irminger Sea, Labrador Sea	Scientific survey	2 trawls/63 individuals	20--55									
Maurolicus muelleri Biological samples from MFRI survey B3-2010	Graded trawl, 9 mm stretched mesh size	SW of Iceland	Scientific survey	12 hauls/2533 individuals	19-66							a=$7.79*10^{-6}$ b=3.13 340 ind with lw-info		Age 1 to 3
Biological samples from IMR 2020 survey *Benthosema glaciale*	pelagic trawl	Norwegian waters March	Scientific survey 578 meters	86 individuals analyzed	19-77	VB **L_{inf}** =98.98 Gompertz **L_{inf}** = 85.30	0.05-4.95			46% undef 8% Males 42% Females		a =$2.43*10^{-6}$ b= 3.36	VB k = 0.1646 Gompertz K = 0.305	Age 2 to 6 IGS (%) = 3.94±1.75
Biological samples from IBWSS 2021 Survey Benthosema glaciale	pelagic trawl 82 m length, fishing circle 768 m, wing mesh size 12.8 m graded through to codend 60 mm	West of Ireland April 1 haul: 60.13ºN-7.55ºW	Opportunistic survey 460 meters Temp 50m: ~8ºC	43 individuals analyzed	43-78	VB **L_{inf}** =87.36 Gompertz **L_{inf}** = 84.26	0.61-5.47 Weight couldn't be very accurate due to poor fish condition			Poor condition		a =$2.24*10^{-7}$ b= 3.89 to be considered with caution	VB k = 0.276 Gompertz K = 0.372	Age 3 to 7 IGS (%) = No information
Catch length distributions from IMR cruise 2016115	Non-graded trawls	Norwegian Sea and Norwegian fjords	Scientific survey	26 trawls/1801 individuals	13-81									
Catch length distributions from IMR cruise 2018106	Non-graded trawls	North Atlantic including Norwegian fjords	Scientific survey	20 trawls/1337 individuals	21-85									
Catch length distributions from IMR cruise 2019703	Non-graded trawl, 8 mm stretched mesh size	Cape Verde to Bay of Biscay	Scientific survey	14 trawls/469 individuals	11-44									

Source & Species	Survey and gear incl. selection parameters	Space and time	Sampling strategy/ Depth/ Temp	Sample size (N)	Observed Standard Length (mm)	Von Bert. L_{inf} (mm)	Weight (g)	Von Bert. W_{inf} (g)	L50/ Maturity/Fecundity (1)	Sex ratio F:M	Natural mortality M (y^{-1})	LW-relationship TW vs SL	Growth parameter k	Other IGS(±SD)$^{(2)}$
Catch length distributions from IMR cruise 2013107	Non-graded trawl, 8 mm stretched mesh size	Norwegian Sea, Iceland Sea, Irminger Sea, Labrador Sea	Scientific survey	29 trawls/2152 individuals	16-84									
Benthosema glaciale Length distributions from MFRI survey A 2019	#1024”. Equipped with multisampler with three codends. Stretched mesh size of coded 23 mm. Vertical opening 45-50 m.	Irminger Sea June -July	Scientific redfish survey Depths from ~250 -850m	29 hauls/ 2296 individuals	24-94							a=1.39*10^{-5} b=2.97 2238 ind with lw-info		
Benthosema glaciale Length distributions from MFRI survey A 2011	#1024”. Equipped with multisampler with three codends. Stretched mesh size of coded 23 mm. Vertical opening 45-50 m.	Irminger Sea June -July	Scientific redfish survey Depths from ~250 -850m	37 hauls/ 1197 individuals	5-90							a=1.81*10^{-5} b=2.89 1166 ind with lw-info		
Benthosema glaciale Length distributions from MFRI survey A 2013	#1024”. Equipped with multisampler with three codends. Stretched mesh size of coded 23 mm. Vertical opening 45-50 m.	Irminger Sea June-July	Scientific redfish survey Depths from ~250 -850m	37 hauls/ 1693 individuals	3-80							a=1.76*10^{-5} b=2.92 1723 ind with lw-info		
Benthosema glaciale Length distributions from MFRI survey A62015	#1024”. Equipped with multisampler with three codends. Stretched mesh size of coded 23 mm. Vertical opening 45-50 m.	Irminger Sea June-July	Scientifc redfish survey Depths from ~250 -850m	37 hauls/ 1693 individuals	10-90							a=1.30*10^{-5} b=2.96 874 ind with lw-info		
Source & Species	Survey and gear incl. selection parameters	Space and time	Sampling strategy/ Depth/ Temp	Sample size (N)	Observed Standard Length (mm)	Von Bert. L_{inf} (mm)	Weight (g)	Von Bert. W_{inf} (g)	L50/ Maturity/Fecundity (1)	Sex ratio F:M	Natural mortality M (y^{-1})	LW-relationship TW vs SL	Growth parameter k	Other IGS(±SD)$^{(2)}$
Benthosema glaciale Biological samples from MFRI survey A72020	Macrozooplankton trawl, 4mm mesh (6mm mesh) trawl opening ~27m^2	Irminger Sea, Reykjanes Ridge, off S-Iceland, July	Opportunistic Scientific survey 4 clusters 3x each: 1. Integrated from 1000m, TS lower 400-570,TS upper : 250-325	12 hauls/582 individuals	Range 8-65, mean= 34		Range 0.1-3.6 mean =0.6 h					a=3.32*10^{-6} b=3.35 324 ind with lw-info		

Source & Species	Survey and gear incl. selection parameters	Space and time	Sampling strategy/ Depth/ Temp	Sample size (N)	Observed Standard Length (mm)	Von Bert. L_{inf} (mm)	Weight (g)	Von Bert. W_{inf} (g)	L50/ Maturity/Fecundity (1)	Sex ratio F:M	Natural mortality M (y^{-1})	LW-relationship TW vs SL	Growth parameter k	Other IGS(±SD)(2)
Benthosema glaciale Biological samples from MFRI survey A72020	Multpelt 832 with 40 mm mesh, trawl opening	Irminger Sea, Reykjanes Ridge, off S-Iceland, July		6 stations/227 individuals	38-85							$a=8.3*10^{-6}$ b=3.06 223 ind with lw-info		

* weight average determined from measurement in bulk divided by total number of fish

(1) Parameters were calculated by pooling samples of *Maurolicus* captured in the Bay of Biscay in April19, May21 and September 16 and 20.

(2)

$$IGS = 100 * \frac{Gonadweight}{EvisceratedWeight}$$

3.3 Additional Relevant Information Available on Key Demographic Parameters for Pearlside (*Maurolicus muelleri*) from Survey Sampling

Biology and key demographic parameters of *Maurolicus muelleri* in the Bay of Biscay. Preliminary results.

By Paula Alvarez, Dorleta Garcia and Guillermo Boyra.

Abstract

Based on the catches of *M. muelleri* made with a pelagic trawl net during the surveys JUVENA (in September 2019/2020), MEGS (in April 2019) and BIOMAN (in May 2020) in the Bay of Biscay, we studied the most relevant biological parameters to assess the feasibility of developing an ecologically sustainable mesopelagic fish fishery. The study presents preliminary data on length distribution, the age, growth, maturity ogive, spawning season, and sex ratio for this species. The results revealed that in spring, the adult spawners (age 1 and 2) are the dominant ones, while in September, they are the juveniles (age 0) born in spring. No fish older than 2 years were found in this area. Growth in weight with length, described by the power equation, varied annually ($\beta = 3.01$ and $\beta = 3.13$ for 2019 and 2020, respectively) but no statistically differences were found between sexes. Using standard lengths, 50% of fish were mature at 34.1 mm (both sexes combined) and the sex ratio, male to female, was 0.44:0.56. The proportion of females increased with length, and a 1:1 sex ratio was predicted at a standard length of 41.5 mm. Most of ripe female fish were found April and May and a few in September. The spawning season occurs, at least, between March and July with a likely peak in May. Batch fecundity ranged from 114 to 919 oocytes/females, and it increased with the weight and the length of females. These results can be considered a significant advance in the knowledge of the biology of *M. muelleri* in this area, despite the fact that some variables, such as age assignation, require more in-depth analysis.

For more information see: Alvarez, A, Garcia, D. and Boyra, G., 2021. Biology and key demographic parameters of *Maurolicus muelleri* in the Bay of Biscay. Preliminary results. Manuscript In Preparation, AZTI, Spain.

4.0 Key Demographic (Biological) Parameters for Pearlside (*Maurolicus muelleri*) Estimated from Survey Data in TropFishR (MEESO Work Package 5)

4.1 Introduction

This section covers key demographic parameters for Pearlside (*Maurolicus muelleri*) estimated from survey data in TropFishR (MEESO Work Package 5). The table below presents the results from highly preliminary initial runs with the TropFishR package (Mildenberger et al. 2017). ELEFAN+ bootstrapping methods were applied to subsets of length frequency data from *Maurolicus muelleri*, from different regions and years. Growth parameters from the Von Bertalanffy equation, and their confidence intervals, were estimated, and for selected subsets also natural Mortality M and selectivity parameter L50. The results in the table below are presented with the main purpose of model calibration and parameter setting, and hence should be treated with extreme caution.

4.2 Initial Results and Overview from TrophFishR Analyses

Table 4.1. TrophFishR initial parameter estimates from survey data of life-history traits and biology of pearlside (*Maurolicus muelleri*) at different locations in different periods of MEESO research survey sampling.

Source & Species	**Survey and gear incl. selection parameters**	**Space and time**	**Sampling strategy/ Depth/ Temperature**	**Sample size (N)**	**Observed Standard Length (mm)**	**Von Bert. L_{inf} (mm)**	**Weight (g)**	**Von Bert. W_{inf} (g)**	**L50/ Maturity/ Fecundity**	**Sex ratio**	**Natural mortality M (y^{-1})**	**LW-relationship**	**Growth parameter k**	**Other**
Maurolicus muelleri, IMR surveys 2016-2018	Macrozooplankton-net, 6x6mm mesh size. Estimated selectivity parameter L50: 2.46 +-0.21	2016-2018, March, June and October		28 hauls, 1359 individuals measured		5.72 +- 0.51					1.95 +- 0.72		0.81 +- 0.39	T0: 0.45 +- 0.18
Maurolicus muelleri, IMR surveys in fjords	Macrozooplankton-net, 6x6mm mesh size. Estimated selectivity parameter L50: 3.28 +- 0.1	2018 (June) , 2020 (March)		7 hauls, 757 individuals sampled		5.05 +- 0.64					2.1 +- 0.69		0.84 +- 0.35	T0: 0.51 +- 0.18
Maurolicus muelleri, IMR surveys in the North Sea	Macrozooplankton-net, 6x6mm mesh size. Estimated selectivity parameter L50: 1.98+- 0.03	2020 (March)		7 hauls		5.82 +- 0.31					1.84 +- 0.64		0.75 +- 0.35	**T0: 0.47 +- 0.17**
Maurolicus muelleri, IMR surveys on the coast of Norway	Macrozooplankton-net, 6x6mm mesh size. Estimated selectivity parameter L50: 2.37 +- 0.22	2016 (October)		16 hauls, 585 individuals sampled		5.78 +- 0.77					1.79 +- 0.86		0.75 +- 0.47	**To: 0.46 +- 0.18**
Maurolicus muelleri, IMR surveys between Iceland and the Faroe Islands	Macrozooplankton-net, 6x6mm mesh size. Estimated selectivity parameter L50: 3.5 +- 0.09	2018 (June)		5 hauls, 170 individuals sampled		5.76 +- 0.63					1.78 +- 0.81		0.71 +- 0.42	**T0: 0.51 +- 0.17**
Maurolicus muelleri,subset of AZTI JUVENA surveys	Graded pelagic trawl with 10mm mesh at codend	2016-2020 (September)		64 hauls, 2155 individuals measured		5.32 +- 0.39							1.56 +- 0.38	**T0: 0.4 +- 0.1**

Source & Species	Survey and gear incl. selection parameters	Space and time	Sampling strategy/ Depth/ Tempera-ture	Sample size (N)	Observed Standard Length (mm)	Von Bert. L_{inf} (mm)	Weight (g)	Von Bert. W_{inf} (g)	L50/ Maturity/ Fecundity	Sex ratio	Natural mortality M (y^{-1})	LW-relationship	Growth parameter k	Other
Maurolicus muelleri, IMR surveys 2008-2012	Macrozooplankton-net, 6x6mm mesh size	2008-2021		92 hauls, 1430 fish measured		5.68 +- 1.03							1.38 +- 0.6	**T=. 0.43 +- 0.15**

4.3 References

Mildenberger, T.K, Taylor, M.H., and Wolff, M. 2017. TropFishR: an R package for fisheries analysis with length-frequency data. Methods in Ecology and Evolution 2017 doi: 10.1111/2041-210X.12791

5.0 Overview of Environmental Data Collated during MEESO Research Surveys Associated to Biological Sampling of Key Demographic (Biological) Parameters (MEESO Work Package 4)

5.1 Introduction

Table 5.1 gives an overview from MEESO WP4 of the different types of environmental data collated during different MEESO research surveys associated to the biological sampling used to determine key demographic parameters presented in Sections 3 and 4 of this report.

5.2 Initial Overview from MEESO WP4 of Environmental Data Collated during MEESO Research Surveys

Table 5.1. Overview table from MEESO WP4 of different types of environmental data sampled during different MEESO research surveys associated to the biological sampling of among other key demographic parameters.

Data Holder & Measurements	**Data Holder** (Institute)	**Environmental Parameters of interest**																			
		CTD measurements							**Water measurements**									**Hyperspectral measurements**		**Observations**	
Survey		Depth	Temperature	Salinity	Oxygen	Fluorescence	Transmittance	Irradiance	Chl a	pH	CDOM	POM	Nitrate	Nitrite	Silicate	Phosphate	Phaephytin	Hyperspectral surface	Hyperspectral water column	Sea state	Cloud cover
JUVENA 2013 - 2020	AZTI	x	x	x	x	x	x	x	x												
JUVENA 2019	AZTI	x	x	x	x	x	x	x	x												
JUVENA 2020	AZTI	x	x	x	x	x	x	x	x												
MEGS (no date?)	AZTI	x	x	x					x												
BIOMAN 2020	AZTI	x	x	x					x												
BIOMAN 2021	AZTI	x	x	x					x												
WESPAS 2020	MI	x	x	x	x	x	-	-	-	-	-	-	-	-	-	-	-	x*	-	-	-
WESPAS 2021	MI	x	x	x	x	x	-	-	-	-	-	-	-	-	-	-	-	x*	-	x	x
IBWSS 2021	MI	x	x	x	x	x	-	-	-	-	x*	-	-	-	-	-	-	x*	-	x	x
SINTEF 2019	SINTEF																				
IMR 2013	IMR	x	x	x	x	X	-	X	x	-	-	x	x	x	x	x	x	x	x	X	X
IMR2016	IMR	x	x	x	-	X	-	X	x	-	-	x	x	x	x	x	x	x	x	X	X
IMR 2018	IMR	x	x	x	x	X	-	X	x	-	-	x	x	x	x	x	x	x	x	X	X
IMR 2019	IMR	x	x	x	x	X	X	X	x	-	-	x	x	x	x	x	x	x	x	X	X
IMR 2020	IMR	x	x	x	x	X	-	X	x	-	-	x	x	x	x	x	x	x	x	X	X
MFRI 2010	MFRI	x	x	x					x											x	x
MFRI 2011	MFRI	x	x	x					x											x	x
MFRI 2013	MFRI	x	x	x					x											x	x
MFRI 2015	MFRI	x	x	x					x											x	x
MFRI 2020	MFRI	x	x	x		x			x			x	x	x	x	x				x	x

* may be obtained from non-MEESO collaborators

Note: The above data is collected seperately and does vary with space and time to fishing data (albeit in most instances not much) and that frequency of data (e.g. amount of CTD casts) varies with survey.

6.0 Key Demographic (Biological) Parameters for Pearlside (*Maurolicus muelleri*) Collated and Estimated from Commercial Fishery Sampling (MEESO Work Package 3 & 5)

6.1 Introduction

Initial parameters obtained so far from outputs on the field campaign data sampling with provision and estimation of initial biological parameters from the commercial fishery sampling associated to the MEESO project (MEESO WP3 & WP5). It should be emphasized that these parameters are initial and only very preliminary and that analyses are still ongoing on the input data from the commercial fishery sampling associated to MEESO. Accordingly, the parameters should be used with great caution.

6.2 Initial Results and Overview from Commercial Fishery Sampling

Table 6.1. Commercial Fishery-available parameters of life-history traits and biology of pearlside (*Maurolicus muelleri*) at different locations in different periods from sampling of commercial fishery.

Source & Species	Survey and gear incl. selection parameters	Space and time	Sampling strategy/ Depth/ Temp	Sample size (N)	Observed Standard Length (mm)	Von Bert. L_{inf} (mm)	Weight (g)	Von Bert. W_{inf} (g)	L50/ Maturity/ Fecundity	Sex ratio	Natural mortality M (y^{-1})	LW-relationship	Growth parameter k	Other
MFRI samples from commercial pearlside fishery 2009	Graded trawls	Fising grounds SW of Iceland	Commercial samples	54 samples/5626 individuals	30-75							$a=5.94*10^{-5}$ $b=2.63$ 198 ind with lw-info		Age 0 to 3
MFRI samples from commercial pearlside fishery 2010	Graded trawls	Fising grounds SW of Iceland	Commercial samples	37 samples/4037 individuals	30-75							$a=6.61*10^{-6}$ $b=3.17$ 90 ind with lw-info		Age 0 to 3
MFRI samples from commercial pearlside fishery 2011	Graded trawls	Fising grounds SW of Iceland	Commercial samples	10 samples/1200 individuals	35-75							$a=4.36*10^{-6}$ $b=3.29$ 450 ind with lw-info		Age 1 to 2

7.0 Initial Commercial Fishing Gear Selectivity Parameters for Pearlside (*Maurolicus muelleri*) and Glacier Lantern Fish (*Benthosema glaciale*) as Estimated from the Fishing Technology Development Work Package 3

7.1 Introduction

This section provides the initial parameters obtained as outputs so far from the MEESO WP3 on fishing technology development for commercial trawl fishing gears with respect to, e.g., gear selectivity parameters.

7.2 Results and Overview of Initial Gear Selectivity Parameters from MEESO WP3

The size selectivity of Pearlsides (*Maurolicus muelleri*) and Glacier Lantern Fish (*Benthosema glaciale*) of three commercial mesopelagic trawl designs used in WP3 (with and without small-mesh liners) was assessed as a function of mesh size (*MS*), tapering angle (α) and mesh opening angle (*OA*) following five key steps:

In *step 1* we used samples of pearlsides collected in July 2019 on board the pelagic trawler "Birkeland" off the western coast of Norway (60°51' N 03°41' E) using a Egersund 1200 m trawl. The samples of glacier lantern fish were collected in 2019, off the coast northern Norway (69˚32' N and 18˚02' E), on board the research vessel "Johan Ruud" using a standard Campelen sampling bottom trawl. All the samples were selected to cover wide span of length sizes.

In *step 2*, we conducted fall-through experiments (Herrmann et al 2012; Herrmann et al 2021) to test which length sizes of fish can geometrically pass through the mesh templates of different *MS* and *OA*. A total of 311 pearlsides and 71 glacier lanternfish were length measured to the nearest mm and presented head first and optimally oriented to 54 different mesh templates. Optimal orientation implies that each fish is positioned in such a way that maximizes its chance to pass through each mesh template (Fig. 3). The mesh templates perforated in 5 mm thick nylon plate (Figure 3) included six different mesh sizes: 6mm, 12mm, 16mm, 20mm, 24mm and 30mm. Some of these mesh sizes corresponded to the mesh sizes of the small-meshed liners used in the trawls. For each mesh size we had nine different opening angles: 10˚, 20˚, 30˚, 40˚, 50˚, 60˚, 70˚, 80˚ and 90˚. The only force acting on the fish was gravity. Whether or not each fish passed through each mesh template was recorded as either a “yes” if it passed through the mesh template, or “no” if it did not (Fig 1).

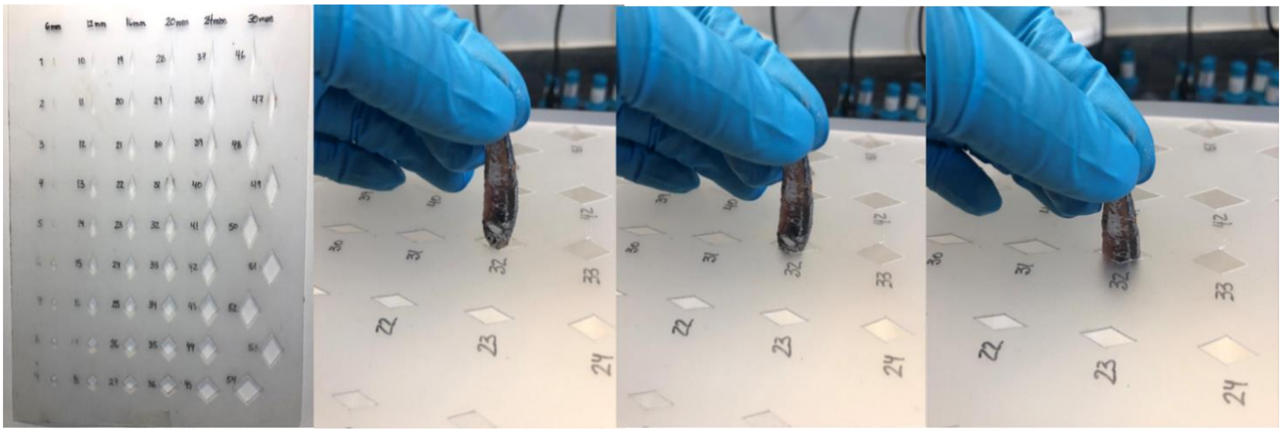

Fig. 1: Fall-through experiment with optimally oriented pearlside.

In *step 3*, for each mesh template and length class (1 mm length class), the number of successful and unsuccessful passes were counted. The data were then treated as covered-codend data (Wileman et al. 1996), where each fish that passed through the mesh template was considered to end up in the cover, while the others were treated as retained in the codend. The following logit size selection model was then fitted to each fall-through dataset to obtain a size selectivity curve for each mesh template:

$$r(L, l50, SR) = \frac{e^{\frac{\ln(9)}{SR} \times (l - l50)}}{1 + e^{\frac{\ln(9)}{SR} \times (l - l50)}} \qquad (1)$$

The *l* in (1) represents fish total length, *l50* the length at which fish has 50% probability of being retained in the codend, *SR* the selection range, which is equivalent to *l75* – *l25*. The estimated *l50* and *SR* values, their covariance matrix, together with the corresponding *MS* and *OA* value for each mesh template were then used to establish the following predictive size selection model:

$$l50 = \alpha_1 \times MS \times OA + \alpha_2 \times MS \times OA^2 + \alpha_3 \times MS \times OA^3 + \alpha_4 \times MS \times OA^4$$

$$SR = \beta_1 \times MS \times OA + \beta_2 \times MS \times OA^2 + \beta_3 \times MS \times OA^3 + \beta_4 \times MS \times OA^4$$

(2)

The $\alpha_1 \ldots \alpha_4$ and $\beta_1 \ldots \beta_4$ in (2) are the model parameters that need to be estimated. All simpler sub-models obtained by leaving out one or more terms at a time from the (2) were also considered for predicting *l50* and *SR* following the procedure described in Brčić et al. (2018) and Herrmann et al. (2021). From the total of 256 models for each species, the model with the lowest AICc value (AICc being the AIC (Akaike 1974) with a correction for finite sample size) was chosen as the best model.

In *step 4,* the best model for each species was applied to predict *l50* and *SR* values for each mesh template used in the fall-through experiment. To check for the model self-consistency, the model predictions were plotted together with their respective 95% confidence intervals against the *l50* and *SR* values estimated by fitting a logit size selection model (1) to each fall-through dataset. In case if predictions represent the trends in the fall-through data well, they were summarized in an isoline graph (lines with equal *l50* values) called the design guides. The design guides depict how *l50* values vary with the change in *MS* and *OA* (Brčić et al. 2018; Herrmann et al. 2021). While performing the fall-through experiments, we assumed that fish are optimally oriented when contacting the mesh. However, during the fishing, meshes are never perpendicular to the natural swimming path of the fish and fish often meet the meshes at suboptimal angle of attack (Fig 4). Fish that are good swimmers and are not exhausted from swimming in front of the trawl prior to entering it, are able to actively change their position to obtain optimal orientation and maximize their escapement probability. Knowing that pearlside and glacier lantern fish grow up to 8 cm and 10 cm, respectively, we assumed they encounter trawl meshes at suboptimal angle of attack (equal to, or close to the tapering angle of the section of the trawl where they encounter the meshes), and do not have enough strength to overcome a strong water flow inside the gear to actively change their position to obtain an optimal orientation and maximize escapement. As angle of attack/ tapering angle is decreasing towards the codend, the projection of the mesh is becoming narrower (Krag et al., 2014; Cuende et al., 2020) and fish are not able to fully utilize the mesh (Fig 2).

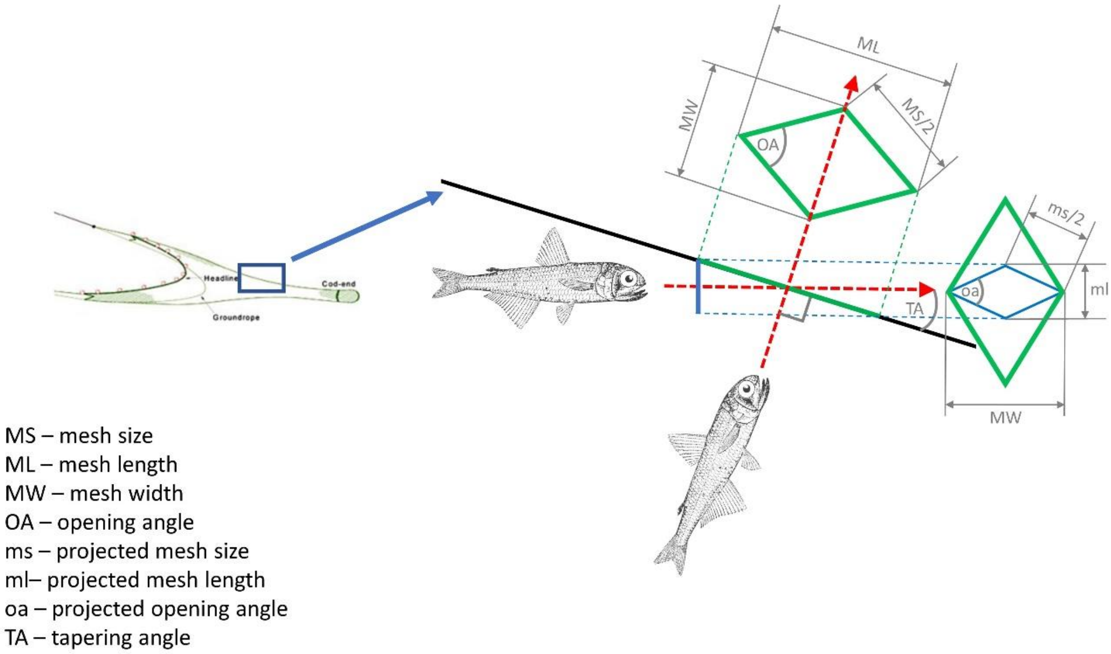

Fig 2. Illustration showing available mesh area as fish meets the mesh at optimal (90°, green) and suboptimal (blue) attack angle.

In *step 5*, we explored the effect of different angles of attack/tapering angles on the size selection of pearl side and glacier lantern fish in trawls. For each mesh size and opening angle considered, we calculated projected mesh size (*ms*) and projected mesh opening angle (*oa*) for different angles of attack/tapering angles (Fig 4) using formulas (3) – (8). Angles considered ranged from 5° to 90°, in steps of 5°.

$$\frac{MW}{2} = \frac{MS}{2} \times \cos\frac{OA}{2} \qquad (3)$$

$$\frac{ML}{2} = \frac{MS}{2} \times \sin\frac{OA}{2} \qquad (4)$$

$$\frac{ml}{2} = \frac{MW}{2} \times \sin TA \qquad (5)$$

$$\frac{mw}{2} = \frac{MW}{2} \qquad (6)$$

$$oa = \tan^{-1}\frac{\frac{MW}{2}}{\frac{ml}{2}} \qquad (7)$$

$$ms = \frac{2 \times \frac{MW}{2} \times \sin TA}{\cos\frac{oa1}{2}}, [oa1 = \min(oa, 180 - oa)] \qquad (8)$$

For the most relevant MSs used in the trawls described in section 2.1 (12, 20, 30 and 40mm) and opening angles ranging from 5-90° the predicted *l50* values using previously obtained each species' best model were summarized in isoline graphs. The dataset resulting from the above procedure was processed using the statistical software tool R (version 4.0.0; R Core Team (2020)). All plots were produced using the ggplot2 package (Wickham 2016).

Based on the fall through measurements we estimate the selection curves for different combinations of mesh sizes and opening angles (Fig. 3).

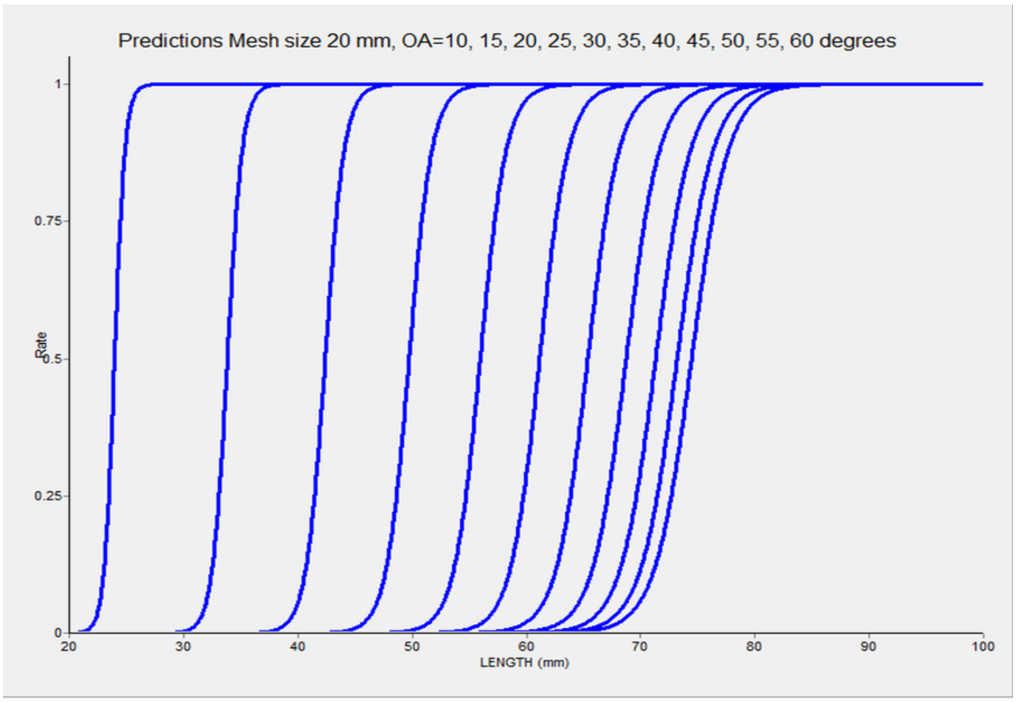

Figure 3. Prediction of selectivity curves for a 20mm mesh size with different opening angles.

A total of 311 pearlsides and 71 glacier lanternfish were used in the fall-through experiments to obtain a fall-through dataset for each of the 54 different mesh templates. This resulted in 16,794 and 3,834 data points for pearlside and glacier lanternfish, respectively. The logit size selection (1) fitted to each of the fall-through dataset allowed obtaining l50 and SR for each mesh template which we subsequently used to establish a predictive model for size selection of pearlsides and glacier lanternfish in trawls. From the total of 256 models tested for each species, the following model yielded smallest AICc value (latter in text referred to as the best model) for both species:

$$l50 = \alpha_1 \times MS \times OA + \alpha_2 \times MS \times OA^2 + \alpha_3 \times MS \times OA^3$$

$$SR = \beta_1 \times MS \times OA + \beta_2 \times MS \times OA^2 \qquad (9)$$

The model coefficients obtained for each species are presented in Table 1.

Table 1. Results for fitting the best model (9) to the fall-through size selectivity data for pearlside and lanternfish. Values in brackets represent 95% confidence intervals.

Species	**Parameter**	**Factor**	**Value**	**P-value**
Pearlside	*L50 (mm)*	α_1	1.35E-0.1 (1.26E-01 – 1.43E-0.1)	<0.0001
		α_2	-1.56E-03 (-1.56E-03 – -1.26E-03)	<0.0001
		α_3	5.73E-06 (3.31E-06 – 8.16E-06)	<0.0001
	SR (mm)	β_1	5.41E-03 (4.41E-03 – 6.42E-03)	<0.0001
		β_2	-4.09E-05 (-5.58E-05 – -2.60E-05)	<0.0001
Lanternfish	*L50 (mm)*	α_1	1.02E-02 (9.51E-03 – 1.10E-02)	<0.0001
		α_2	-1.07E-07 (-1.31E-04 – -8.29E-05)	<0.0001
		α_3	3.70E-07 (1.80E-07 – 5.60E-07)	<0.0001
	SR (mm)	β_1	1.04E-03 (7.10E-04 – 1.36E-03)	<0.0001
		β_2	-8.71E-06 (-1.33E-05 – -4.17E-06)	<0.0001

Using the best predictive model (9), the following design guides (Figure 4A & 4B) were created depicting the effect of mesh size and mesh opening on size selection of pearlsides and glacier lanternfish optimally oriented when encountering trawl meshes. From both figures, we can see that decrease in mesh opening angle from 90° to ~40° has negligible effect on the L50 values for both species. Further decrease in opening angle results in lower L50 values. The increase in mesh size from 5 mm to ~30 mm results in greater increase in l50 values, compared to the same increase in mesh size in the ~30 mm to 60 mm range.

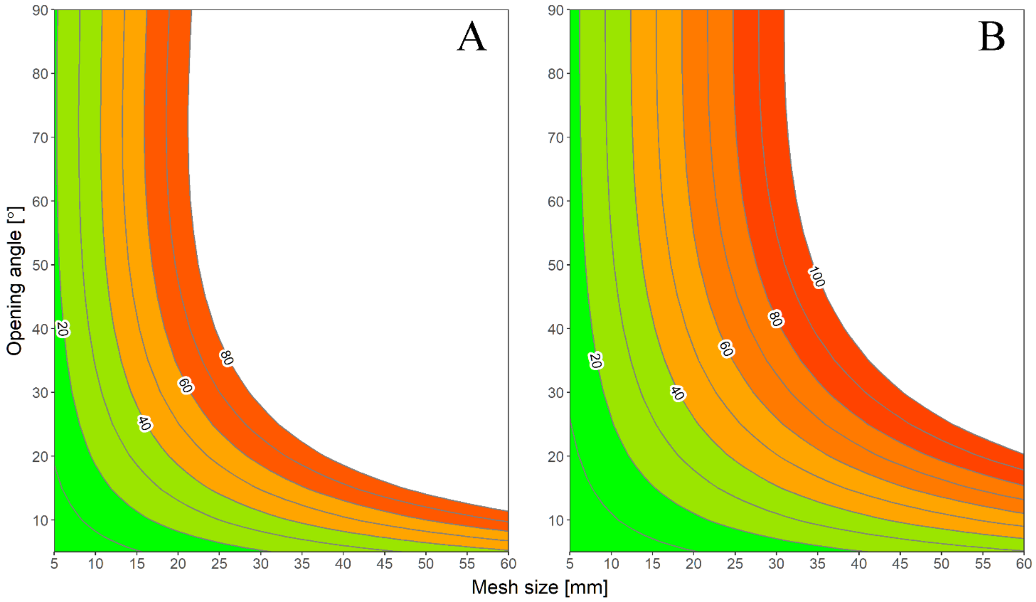

Fig 4: Design guides showing the effect of MS and OA on L50 values for optimally oriented pearlside (A) and glacier lanternfish (B). Considering that pearlside and glacier lanternfish grow up to 8cm and 10cm, respectively, more pronounced red color on the plot indicates greater catch loss of the species.

Figures 5 & 6 illustrate how l50 values vary with the change in mesh opening angle and angle of attack for selected mesh sizes for pearlside and lanternfish, respectively. From both figures it is evident that lower mesh sizes (12mm and 16mm) are more suitable options for catching both species.

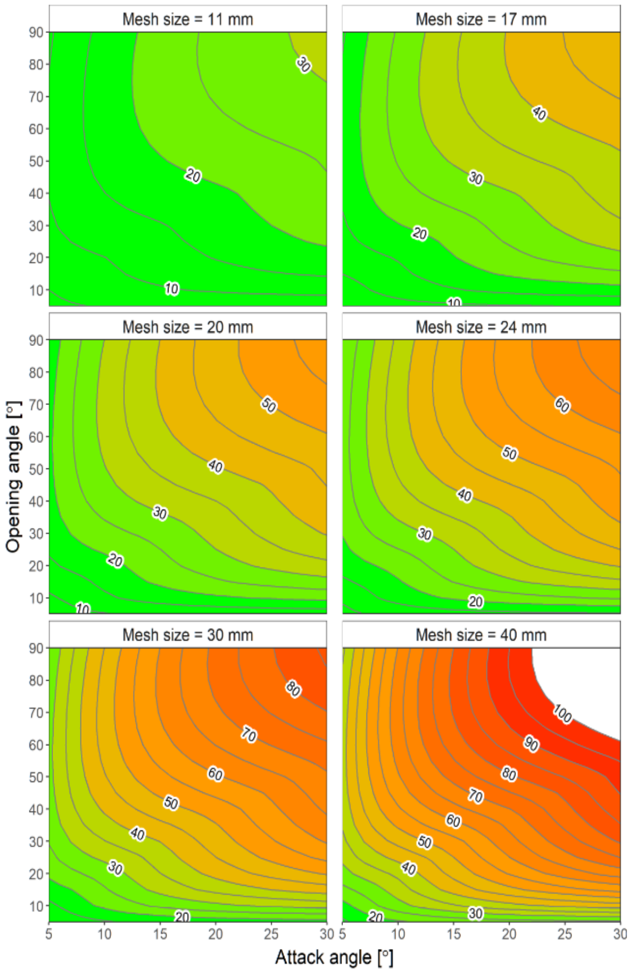

Figure 5. Predicted l50 values for Muller's pearlside (in mm) for different attack angles and mesh opening angles for selected mesh sizes (11 mm, 17 mm, 20 mm, 24 mm, 30 mm, 40 mm). Considering that pearlside grows up to 8cm, more pronounced red color on the plot indicates greater catch loss of the species.

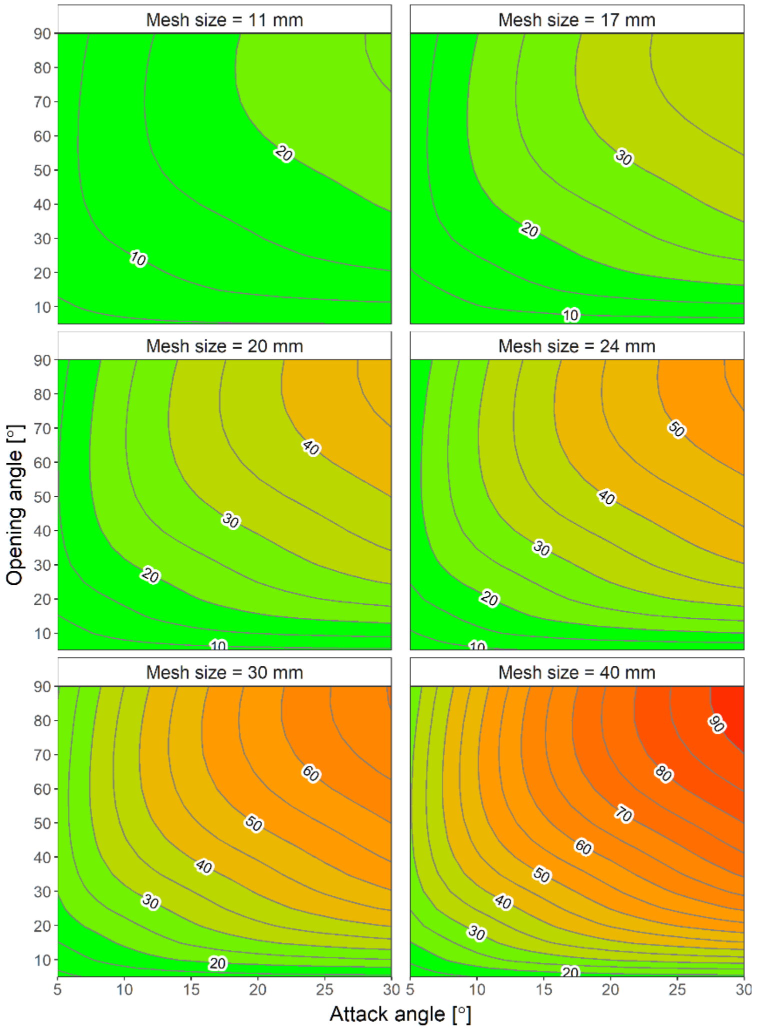

Figure 6: Predicted l50 values for glacier lanternfish (in mm) for different attack angles and mesh opening angles for selected mesh sizes (11 mm, 17 mm, 20 mm, 24 mm, 30 mm, 40 mm). Considering that glacier lanternfish grows up to 8cm, more pronounced red color on the plot indicates greater catch loss of the species.

7.2 References

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