Short report

Northern outpost for Mediterranean scaldfish; Encounters from Norwegian coastal and oceanic waters, NE Atlantic Ocean

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Abstract

Mediterranean scaldfish *Arnoglossus laterna* (Walbaum, 1792) is distributed in the eastern Atlantic, from Angola, via Mediterranean and Black Sea, north to Norway. While is used for human consumption in southern parts, it is considered a non-commercial flatfish in the North Sea. It is rarely reported from its northern outpost, Norwegian waters. Knowledge on biology, habitat, location of spawning areas, larval distribution, and juveniles nursery grounds in North Sea is limited.

We include observations of *A. laterna* from 1876 to 2023 from a pool of both published and unpublished sources, along the Norwegian coast. Frequency distributions from Institute of Marine Research (IMR) data of adults show highest encounters with specimens collected between 30-40 m depth, weighing 6-9 g and measuring between 6-11 cm in total length. Eggs and larvae were observed in both offshore and inshore waters between April and November. One larva recorded in Vestland County (Haganes, Bergen) was found as shallow as 20 cm depth swimming close to the ctenophore *Mnemiopsis leidyi* A. Agassiz, 1865, likely hiding from predators. Both blue and yellow bioluminescent spots on the larva were observed, visible as two bands on the dorsal- and anal fins. This larva specimen was preserved for barcoding (using sequences COI, ITS1, ITS2 and 16S), confirming the morphological identification. The largest specimen obtained in this study (from Arendal) measured 26.5 cm in length, and is probably the largest individual ever recorded, indicating good conditions for growth.

Key words

Arnoglossus laterna, North Sea, Norwegian Sea, DNA, habitat, distribution

Introduction

Mediterranean scaldfish *Arnoglossus laterna* (Walbaum, 1792) is distributed in the eastern Atlantic, from Angola, via Mediterranean and Black Sea, north to Mid-Norway (northern North Sea, into the Norwegian Sea), from 10 to 400 m depth (Dannevig 1960; Tous et al. 2014; Carpenter and Angelis 2016). It is used for human consumption in southern parts of the distribution area but considered a non-commercial flatfish in the North Sea. Although several studies exist on biology on *Arnoglossus* from southern European parts of its distribution area (e.g. Turkey and southern North Sea), there are few studies from its northern outpost, Norwegian waters.

Knowledge on abundance and distribution of eggs and larvae of fish are useful in identifying possible spawning- and nursery grounds, as well as understanding the dynamics of fluctuating populations of fish species in relation to biological and physical processes, including climate changes with increasing water temperatures. *A. laterna* is a predator on, and a considerable competitor to, early juveniles of some commercial fish species, e.g. Pleuronectids (Rogers 1991; Schückel et al. 2011). Thus, monitoring its presence may be of importance regarding fisheries on other commercial flatfish species, like halibut. Populations of *A. laterna* are also found to be extending its distribution northwards due to climate change due to increasing water temperatures, and may carry infectious metazoan parasites known to e.g. exhibit immunological response in fish (Overstreet 1992; van Hal et al. 2010; Güven and Öztürk 2019). Hence, the distribution of *A. laterna* may be relevant to monitor for example to the aquaculture industry.

Angola and the Mediterranean Sea

Arnoglossus laterna is edible, and caught for human consumption in e.g. western Africa in artisanal and industrial fisheries, but this small, left-eyed flounder with a thin body has minor commercial importance (Tous et al. 2014). There are several studies, especially from Turkey, on growth and mortality for *A. laterna* as summarized in Ilhan (2010) and Ilkyaz et al. (2017), where e.g. gonad maturity was 11.88 cm (Total Length, TL) for females and 11.41 cm (TL) for males. Also, a seasonal ichthyoplankton study where pelagic *A. laterna* larvae was present during spring only (Hossucu and Ak 2002).

North of the Mediterranean Sea

Portuguese and Spanish studies have focused on e.g. distribution and abundance, where Tagus and Sado estuaries and Ria of Vigo are recognized nursery areas (Ferreiro and Labarta 1988; Cabral 2000; Cabral et al. 2002; Prista et al. 2003; Paulo-Martins et al. 2011), as opposed to e.g. Cadiz (SW Spain) showing a clear pattern of summer-increase of juveniles (Catalán et al. 2006). *A. laterna* is the most abundant fish of the order Pleuronectiformes in the Galician shelf, and is considered a medium-outer shelf group (125-250 m) (Fernández-Zapico et al. 2017).

Studies on distribution and abundance from the United Kingdom (including Irish Sea and Rockall Plateau), indicate spawning of fish from Scotland in the period June to August when 6-7 cm in TL (Dickson et al. 1892; Gibson and Ezzi 1980; Rogers 1991, 1998; Ellis and Rogers 2004; Neat and Campbell 2011), also within spawning period from April to August, in Nielsen (1986). In the context of climate changes with warmer seawater temperatures, distribution of demersal fish assemblages has been studied, where main abundance of *A. laterna* (a warm-favouring species of Lusitanian origin) show a shift of populations northwards (Perry et al. 2005; Heath et al. 2012; Gordó-Vilaseca et al. 2023).

Southern and Central North Sea

Arnoglossus laterna is considered a non-commercial flatfish in the North Sea (van Hal et al. 2010), and is most abundant in the southern parts of the North Sea (Knijn 1993; Callaway 2002; Heessen et al. 2015; Macher et al. 2020). The species is abundant on Dogger Bank, and within Dutch and German exclusive economic zones (EEZs) (Teal et al. 2009; Sonnewald and Türkay 2012; Sell 2013). Coastal areas of the southern North Sea are important nursery areas, for both adults and juveniles (van der Land 1991; Baltus and van der Veer 1995; van Hal et al. 2010; Macher et al. 2020). On Dogger Bank, climate change and fisheries affect the composition of benthic organisms, and *A. laterna* shows both a negative correlation with increasing trawling activity and a geographical shift northwards in this region (Perry et al. 2005; van Hal et al. 2010; Gordó-Vilaseca et al. 2023; Hahn et al. 2023).

In Denmark, *A. laterna* is commonly found around Skagerrak and Kattegat, with increasing abundance into the Baltic Sea (Casini et al. 2005; Frelat et al. 2018; Carl 2019). It has been reported from Syltø-Rømø Bight (Asmus et al. 2020; Odongo et al. 2024). However, it is rarely reported from the Danish beach zone, and has never been reported during «Fish atlas» (Fiskeatlasset) regular snorkeling survey along the Danish coasts (Carl

2019). «Fiskeatlasset» is an atlas on Danish saltwater fish collected betwen 2009-2019, in cooperation with Zoological Museum (Copenhagen), Technical University of Denmark (Aquatic Institute) and Krog Consult (https://fiskeatlas.ku.dk/om/). On the west coast of Sweden, *A. laterna* is considered a marine adventitious visitor, showing a preference for soft substrate, and it has been recorded both inshore and offshore (Pihl and Wennhage 2002; Svedang 2003). Also, a Biological recipient control Report exist on increasing populations from 2004 to 2015 around Värö, south of Gothenburg (Lingmann and Sundquist 2016).

Observations in northern North Sea and Norwegian Sea

Arnoglossus laterna is considered a rare, non-commercial fish in Norwegian waters, which has been infrequently reported from scientific cruises, and is considered to be part of the southern North Sea fauna, up to 57ºN (Dannevig 1960; Johannessen and Sollie 1994; Sollie 1995, 1998; Albert et al. 1998; Olsgaard et al. 2002; Gjøsæter 2008; Anonymous, IMR 2011; Skants 2019; Krafft et al. 2021; Søvik et al. 2023; Vøllestad 2023).

To procure baseline data of a poorly known species, we report on egg, juvenile and adult *A. laterna* from Norwegian waters, collected from a pool of published and unpublished sources from 1876 to 2023. The frequencies of biotic factors (weight, length and depth) on a time-series collected by scientific cruises are also included.

Materials and methods

Area

North Sea lies on the European continental shelf (between ~51º- 61ºN), with a mean depth of 90 m, and may be divided into southern-, central- and northern parts (Anonymous, IHO 2002; Walday and Kroglund 2002; ICES 2023). North of the North Sea (north to ~71ºN) lies the much deeper Norwegian Sea with a mean depth of 1600 m (Helland-Hansen and Nansen 1909; Anonymous, IHO 2002).

The Norwegian EEZ covers an area of roughly 965 000 km2 (Harsson and Preiss 2012). The coastal water (the Norwegian Coastal Current, NCC) flows northwards along the coast of Norway as a low-

salinity current. It originates from a mixture of brackish water from the Baltic Sea, also fed by Norwegian rivers along the coast, varying greatly in temperature from summer to winter (Sætre 2007; Albretsen et al. 2012). Beyond and beneath the coastal water, from around Mid-Norway, we find Atlantic Water, entering the North Sea north of Shetland. Atlantic Water is higher in salinity and with relative stable and high temperatures. Below the Atlantic Water is the Intermediate Water, fresher and cooler than Atlantic Water (Ådlandsvik et al. 2015).

Pool of sources

We collected data from a pool of sources, including our own data, as well as conducted literature- and citizen science searches online, mainly using search engines like Google, Google Scholar and Facebook.

During five plankton cruises carried out by Institute of Marine Research (IMR) in Bergen, Norway, several gear types were used: 1) Methot Isaac Kidd Midwater trawl (MIK), 2) Gulf III plankton sampler, and 3) Turtox plankton tow net (T-80) which are standard gear for sampling of North Sea larvae (Hassel et al. 2013). The MIK trawl consisted of a rigid 2 m metal frame to which a 14 m long nylon net (mesh size 1.2 mm) was attached. At the rear, a 1.5 m long conical, 500 µm plankton net is attached before the cod end. Towing speed is 3 knots. The Gulf III is a high-speed torpedo-shaped aluminium sampler, about 2 m in length with a 19 cm diameter opening and inner net (375 µm), towed at 5 knots. It is lowered and lifted (vertically) while the boat is moving. The T-80 (80 cm diameter ringnet) is lowered and lifted (vertically), while the boat is at rest. Once onboard, all larvae were handled after procedures in Hassel et al. (2013). Individuals at the same station (apart from during ichthyoplankton cruises) were collectively weighed to the nearest 1 g (wet weight), and total length was measured to the nearest cm. During this study, total weight was divided by number of specimens (n) at each station (providing average individual weight) prior to setting up frequency distributions.

Bottom- and shrimp trawls, scallop dredge, and beach seine were also used during other IMR cruises, all mentioned in Mjanger et al. (2023). Bottom trawl Grande Ouverture Verticale (GOV-trawl) is a sampling trawl used during International Young Fish Survey (IYFS) in the North Sea, and shrimp trawl type were of

Campelen 1800 20/40 with rockhopper gear. Danish sledge is a scallop dredge with a net used for sampling of benthos, and the beach seine is a seine net operated from the shore.

One larva was observed (by the author HR) in the Bergen area (Vestland, Sotra, Haganes) 26 August 2023. It was caught with a dip net at about 20 cm depth at a boat pier. The specimen was gently placed in a plastic box before transported to the nearby laboratory where it was measured with a ruler (live, in sea water), photographed, seduced and preserved in 90% ethanol for DNA analysis. The temperature of the surface water was measured five days later with a hand-held thermometer, considering to be the same as on the day of capturing the larva.

Morphological and molecular identification

The adults of *A. laterna* are oval bodied, left eyed, with lateral line curving above the pectoral fin, and with base of the left pelvic fin larger than of the right pelvic fin, and the pelagic larva is distinguished by its characteristic large fin ray above the head, with sparse pigmentation (Munk and Nielsen 2005). Munk and Nielsen (2005) and Pethon (2019) were used for identification of specimens based on morphology. Identification of the larva from Haganes was confirmed using molecular methods. DNA was extracted from the larva following the protocol of the DNA NucleoSpin Tissue kit (Macherey-Nagel, REF: 740952.250). Extracted DNA was run in separate PCR using the following three primer pairs. Animal mtDNA COI region was amplified using jgLCO1490 5'-TITCIACIAAYCAYAARGAYATTGG-3' and jgHCO2198 5'-TAIACYTCIGGRTGICCRAARAAYCA-3' (I stands for inosine; (Geller et al. 2013), ITS region using primer pair SR6R 5'-AAGWAAAAGTCGTAACAAGG-3' (Prudkovsky et al. 2019) and LR1 5'-GGTTGGTTTCTTTTCCT-3' (Vilgalys and Hester 1990), and finally, animal 16S rRNA region using primer pair 16SaR 5'-TCGACTGTTTACCAAAAACATAGC-3' and 16SbR 5'-ACGGAATGAACTCAAATCATGTAAG-3' (Cunningham and Buss 1993).

The reaction setup followed Kankaanpää et al. (2020) and included 6 microliters of 2× MyTaq HS Red Mix (Bioline, UK), 3.2 microliters of sterile water, 0.33 mM each primer (forward and reverse), and 2 microliters of DNA template per each reaction in 12 microliter volume. Cycling conditions were the same for all primers: initial denaturation for 2 min at 95 °C, followed by 40 cycles of 40 seconds at 95 °C (denaturation), 40 seconds at 50 °C

(primer annealing), and 1 min at 72 °C (extension), ending with final extension step 5 min at 72 °C. PCR products were purified by the A'SAP clean kit (product nr 80350, ArcticZymes, Tromsø, Norway). Purified samples were sequenced for both directions at Macrogen Europe B.V (Amsterdam, the Netherlands). The resulting sequences were trimmed for the primers and low-quality regions using software Geneious (Kearse et al. 2012). The sequences were identified by comparing them against BOLD (Ratnasingham and Hebert 2007) using the online ID engine tool, and against GenBank using BLAST (Altschul et al. 1990).

Results and discussion

Adult distribution

Through a pool of published and unpublished sources (from 1876 to 2023), including our own data, *A. laterna* has been recorded from Østfold county and the Oslofjord in the southeast, north to Mid-Norway (Trondheimsfjord, 63,6ºN) (Table 1 a-c, Fig. 1). A few recordings from Troms (70ºN) and Nordland counties (67ºN) exists (IMR data), but these are omitted in Table 1 due to probably erroneous species identification. In the southern parts of Norway (Oslofjord), relatively few specimens have been recorded, both from inner and outer Drøbak sound (Hjort and Ruud 1938; Lid 1967; Haaverstad 2007).

Norway is truly a northern outpost for *A. laterna*, often with single specimens recorded at each location/ station only, compared with frequent recordings in southern North Sea or the Mediterranean Sea (van Hal et al. 2010; Macher et al. 2020). For example, only four specimens of *A. laterna* were recorded by the IMR offshore demersal reference fleet in 2010, while in comparison a total of 2,758 specimens of another flatfish, *Hippoglossus hippoglossus* (Linnaeus, 1758) was recorded (Anonymous, IMR 2011). *A. laterna* was also absent from IMR pelagic and coastal reference fleets the same year (op. cit.).

Table 1 Recordings of adult *Arnoglossus laterna*, mainly from IMR cruises during 1994–2022 within Norwegian waters. Columns include date, type of cruise, approximate latitude and longitude (DD, at start of haul), gear type, depth (m, at start of haul), amount, total wet weight of all specimens at the station (kg) and comments/references

Date	Cruise	Latitude	Longitude	Gear type	Depth	Amount	Total weight	Comments/ references
1994	Sørlandet							Johannessen and Sollie (1994)
1995	Kristiansand-Hvaler							Sollie (1995)
15.09–02.10.1998	Torvefj-Oslofj-Hvaler					2		Mission with the cruise; mapping juvenile fish in the beach sone; Sollie (1998)
7/12/2005	IMR 2005617	60.6933	−0.2867	GOV trawl	95	1	0.003	Mission with the cruise; IBTS-labelling of monkfish
5/9/2006	IMR 2006207	55.3433	3.9183	Danish sledge	31	1	0.016	Mission with the cruise; monitoring plankton
5/9/2006	IMR 2006207	55.3150	3.8850	Danish sledge	36	1	0.007	Mission with the cruise; monitoring plankton
5/9/2006	IMR 2006207	55.3417	3.8550	Danish sledge	28	10	0.094	Mission with the cruise; monitoring plankton
5/1/2007	IMR 2007205	55.3250	1.6467	Danish sledge	42	3	0.019	Mission with the cruise; sandeel and plankton
5/1/2007	IMR 2007205	54.9900	1.8283	Danish sledge	25	2	0.017	Mission with the cruise; sandeel and plankton
5/4/2007	IMR 2007205	55.7900	5.0617	Danish sledge	34	1	0.024	Mission with the cruise; sandeel and plankton
5/4/2007	IMR 2007205	55.8950	5.1533	Danish sledge	37	1	0.009	Mission with the cruise; sandeel and plankton
Nov 2007	Hvasser	59.0700	10.4500			2		Gjøsæter (2008)
4/28/2008	2008205	55.7283	4.9083	Danish sledge	37	2	0.004	Mission with the cruise; sandeel and plankton
4/28/2008	2008205	55.7400	4.9467	Danish sledge	36	2	0.013	Mission with the cruise; sandeel and plankton
4/29/2008	2008205	55.7467	4.8933	Danish sledge	36	1	0.003	Mission with the cruise; sandeel and plankton
4/29/2008	2008205	55.7567	4.9217	Danish sledge	36	3	0.018	Mission with the cruise; sandeel and plankton
4/29/2008	2008205	55.7583	4.9300	Danish sledge	36	1	0.001	Mission with the cruise; sandeel and plankton
4/29/2008	2008205	55.7283	4.9100	Danish sledge	37	1	0.021	Mission with the cruise; sandeel and plankton
4/30/2008	2008205	55.7600	4.9267	Danish sledge	36	1	0.001	Mission with the cruise; sandeel and plankton
5/4/2008	2008205	55.2817	1.4317	Danish sledge	44	1	0.011	Mission with the cruise; sandeel and plankton
5/4/2008	2008205	55.0483	1.3550	Danish sledge	25	13	0.075	Mission with the cruise; sandeel and plankton
5/4/2008	2008205	54.9983	1.8217	Danish sledge	22	1	0.005	Mission with the cruise; sandeel and plankton
5/5/2008	2008205	54.6500	1.5750	Danish sledge	21	2	0.015	Mission with the cruise; sandeel and plankton
5/5/2008	2008205	54.8567	1.2600	Shrimp trawl	38	15	0.135	Mission with the cruise; sandeel and plankton
5/5/2008	2008205	54.4483	1.8667	Danish sledge	26	2	0.003	Mission with the cruise; sandeel and plankton
5/6/2008	2008205	54.1333	2.1067	Danish sledge	23	2	0.016	Mission with the cruise; sandeel and plankton
5/6/2008	2008205	54.5567	1.2600	Danish sledge	29	3	0.016	Mission with the cruise; sandeel and plankton

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Table 1 (continued)

Date	Cruise	Latitude	Longitude	Gear type	Depth	Amount	Total weight	Comments/ references
5/6/2008	2008205	54.5617	1.2617	Danish sledge	22	1	0.008	Mission with the cruise; sandeel and plankton
5/6/2008	2008205	54.5133	1.6867	Danish sledge	18	1	0.002	Mission with the cruise; sandeel and plankton
5/6/2008	2008205	54.4600	1.8550	Danish sledge	18	2	0.013	Mission with the cruise; sandeel and plankton
5/6/2008	2008205	54.6000	2.6967	Danish sledge	21	2	0.01	Mission with the cruise; sandeel and plankton
5/6/2008	2008205	54.7033	2.7767	Danish sledge	18	3	0.016	Mission with the cruise; sandeel and plankton
5/7/2008	2008205	54.4667	2.2967	Danish sledge	16	2	0.008	Mission with the cruise; sandeel and plankton
5/7/2008	2008205	54.4600	2.0850	Danish sledge	15	3	0.025	Mission with the cruise; sandeel and plankton
5/7/2008	2008205	54.4683	2.3000	Danish sledge	17	1	0.009	Mission with the cruise; sandeel and plankton
5/7/2008	2008205	55.4317	4.1817	Danish sledge	30	1	0.006	Mission with the cruise; sandeel and plankton
5/8/2008	2008205	55.3200	3.8633	Danish sledge	30	1	0.009	Mission with the cruise; sandeel and plankton
5/8/2008	2008205	55.1983	3.6217	Danish sledge	27	4	0.044	Mission with the cruise; sandeel and plankton
5/8/2008	2008205	55.3233	3.8717	Danish sledge	31	2	0.016	Mission with the cruise; sandeel and plankton
5/8/2008	2008205	55.7400	4.9617	Danish sledge	35	1	0.014	Mission with the cruise; sandeel and plankton
5/9/2008	2008205	55.9267	5.1700	Danish sledge	40	2	0.006	Mission with the cruise; sandeel and plankton
5/13/2008	2008205	57.0333	7.1183	Danish sledge	24	1	0.017	Mission with the cruise; sandeel and plankton
2/22/2010	IMR 2010102	56.8833	6.3033	GOV trawl	46	1	0.014	
5/3/2015	IMR 2015837	56.8308	3.6945	Danish sledge	61	1	0.019	Mission with the cruise; sandeel measurements
9/25/2017	IMR 2017314	59.0497	9.7600	Beach seine		1		Mission with the cruise; ocean acidity and microplastics
9/27/2017	IMR 2017314			Beach seine		1		
9/29/2017	IMR 2017314	59.2657	10.7365	Beach seine		1		
11/3/2017	IMR 2017620	62.5734	7.7443	Shrimp trawl	37	1	0.006	Mission with the cruise; acoustics, seith, cod and haddock
2017	IMR cruise, UiB	62.5772	7.735277		36	1		Skants (2019), location Romsdalsfjord
9/21/2018	IMR 2018316	58.7215	9.2028	Beach seine		1		
9/22/2018	IMR 2018316	58.8345	9.3188	Beach seine		1		
2/17/2022	IMR 2022	61.9760	5.0073	Danish sledge	55–60	1	0.002	Søvik et al. (2023), Ecosystem cruise, tobis dredge, Vågsøy, Vestland

IMR Institute of Marine Research, *NTNU* Norwegian University of Science and Technology, *VIMU* University Museum, *UiO* University of Oslo, *NHM* Natural History Museum, *UiB* University of Bergen, *UM* University Museum, *NBIC* Norwegian Biodiversity Information Centre, *NZF* Norwegian Zoological Organization, *gbif* the Global Biodiversity Information Facility

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Table 2 Recordings of adult *Arnoglossus laterna*, mainly by Universities/ institutions and Citizen Science from 1876 to 2023 within Norwegian waters. Columns include institution, observer, observation date and location, amount, approximate latitude and longitude, gear types, depth (m), comments, references

Institution	Observer	Date	Location	Amount	Latitude	Longitude	Gear types	Depth	Comments	References
NHM, UiO	Collett	05.10.1876	Ormøya, Oslofjord	1	59.8781	10.7564				NHM, UiO
NHM, UiO	Collett	07.10.1879	Lysaker, Oslofjord	1	59.9060	10.6442				NHM, UiO
NHM, UiO	G.O.Sars	July 1883	Skjærhallen, Hvaler	1	59.0182	10.8784				NHM, UiO
NHM, UiO	G.O.Sars	August 1885	Merdø, Arendal	1	58.4333	8.9621				NHM, UiO
NHM, UiO	?	16.09.1891	Oslofjord	7						NHM, UiO
UM, UiB	Collett	22.02.1892	Oslofjord							UM, UiB
UM, UiB	Collett	28.09.1896	Oslofjord							UM, UiB
NHM, UiO	Collett	12.05.1897	Sandvika, Oslofjord	1	59.8891	10.5409				NHM, UiO
NHM, UiO	Hjort	06.08.1898	Risavika, Tananger, Sola	2	58.8859	5.3467				NHM, UiO
NHM, UiO	Hjort	29.09.1898	Langesundsfjorden, Bamble	1	59.0074	9.5590				NHM, UiO
NHM, UiO	Collett	5/22/1903	Fredrikstad	1	59.1923	10.8566				NHM, UiO
NHM, UiO	?	3/24/1905	Hvaler	1	59.0182	10.8784				NBIC
UM, UiB	Bergen Museum biol. St	8/27/1930	Hjeltefjord, Vestland		60.4000	5.1000				UM, UiB
NTNU-VIMU	Knut Hegge	8/14/1933	Beian, Ørlandet	1	63.6488	9.5654			Length 7.5 cm	NBIC, gbif
NHM, UiO	Dr. G. Krefft	1/16/1957	Moss	6	59.4667	10.8333		36		NBIC
NHM, UiO	Kristiansen	12/5/1966	Holmestrandsrenna, Vestfold	1	59.4800	10.3800	Trawl	200		NHM, UiO; Lid (1967)
NHM, UiO	Kristiansen	1/8/1967	Holmestrandsrenna, Vestfold	1	59.4800	10.3800	Trawl	60		NHM, UiO; Lid (1967)
NMH, UiO	Kristiansen	3/2/1967	Bunnefjorden, Oslo	1	59.7900	10.7200	Trawl	60		NHM, UiO; Lid (1967)
NHM, UiO	Gramum	3/2/1967	Østskjær, Horten	5	59.4060	10.4665	Trawl	60		NHM, UiO; Lid (1967)
NHM, UiO	Gramum	3/7/1967	Østskjær, Horten	1	59.4060	10.4665	Trawl	60		NHM, UiO; Lid (1967)
NHM, UiO	Kristiansen	3/13/1967	Bunnefjorden, Oslo	1	59.7900	10.7200	Trawl	60		NHM, UiO; Lid (1967)
NHM, UiO	Kristiansen	3/14/1967	Østskjær, Horten	3	59.4060	10.4665	Trawl	80		NHM, UiO; Lid (1967)
NHM, UiO	Gramum	3/28/1967	Kommersø, Holmestrand	1	62.2796	5.3185	Trawl	75		NHM, UiO; Lid (1967)
NHM, UiO	Terje Laskemoen	6/25/2009	Oven, Råde		59.3094	10.7413			COI sequence, Bold: NOFIS055-10	NBIC
NHM, UiO	Terje Laskemoen	6/25/2009	Oven, Råde		59.3094	10.7413				NBIC
NZF	Espen Krogh	7/29/2012	Sandefjordsfj, Sandefjord	1	59.1280	10.1501	Fishing	10		NBIC, Citizen Science
NZF	Espen Krohg	6/12/2013	Sandefjordsfj, Sandefjord	1	59.1280	10.1501	Fishing			NBIC
NZF	Espen Krohg	6/15/2015	Sandefjordsfj, Sandefjord	3	59.1280	10.1501	Fishing			NBIC

Table 2 (continued)

Institution	Observer	Date	Location	Amount	Latitude	Longitude	Gear types	Depth	Comments	References
	Aspen	June/Aug – 2015	Sandefjordsfj	5	59.0800	10.2400	Fishing	7–15	5 specimens caught in three years	Citizen Science
	Bjørn Bakkelid	30.08.2015	Engelsviken, Sarpsborg	1	59.2400	10.7200	Fishing			
	Magnus Durell, Thomas Rødskjær	8/13/2016	Langesund	2	58.9800	9.7300	Fishing			Citizen Science
Nifes report		22–26.09.2016	Årdalstangen, Årdalsfj	4	61.2333	7.6833			4 (?) specimens	Kögel et al. (2017)
	Nils Aukan	1/9/2017	Glærum, Møre	1	62.9800	8.6100	Diving			Citizen Science
NZF	Albin Dal	7/27/2018	Helgeroa, Larvik	1	58.9900	9.8530				NBIC
	Nils Aukan	11/7/2018	Batnfjord, Møre	1	62.9000	7.6900	Diving			Citizen Science
NZF	Espen Krogh	5/15/2019	Sandefjordsfj, Sandefjord	12	59.1280	10.1501	Fishing			NBIC
	AFK Nemesis	9/4/2019	Sandefjord	1	59.0800	10.2400	Fishing			Citizen Science
NZF	Johan Svensson	9/28/2019	Havsøysund, Arendal	1	58.4219	8.7716				NBIC
NZF	Erling Svensen	10/16/2019	Dyrnes, Egersund	1	58.4169	6.0106	Diving	25		NBIC
	Asgeir Alvestad	11/20/2019	Sandefjordsfjord	2	59.0800	10.2400	Fishing		Relatively common in certain areas	Citizen Science
NZF	Rune Skålland	2/19/2020	Fladeviga, Heimarnes, Arendal	1	58.4194	8.7562				NBIC
NZF	Espen Krogh	3/10/2020	Sandefjordsfj, Sandefjord	10	59.1280	10.1501	Fishing	?		NBIC
NZF	Erling Svensen	1/26/2021	Forsand, Sandnes	3	58.8961	6.0946	Diving	– 25		NBIC
NZF	Espen Krogh	6/1/2021	Sandefjordsfj, Sandefjord	5	59.1280	10.1501	Fishing			NBIC
	Nils Aukan	6/28/2021	Glærum, Møre	1	62.9800	8.6100	Diving			Citizen Science
	Asgeir Kvalsund	10/9/2021	Kristiansand	1	58.1300	8.0200	Fishing			Citizen Science
	MS Vassfis	7/11/2021	Arendal	1	58.4186	8.7498	Baited hook		26.5 cm in length	imr.no, "Dugnad for havet", verified by author TM
	Ole-Håkon Heier	9/16/2023	Singlefjorden, Sarpsborg	1	59.0971	11.1686	Fishing	13		gbif.org

IMR Institute of Marine Research, *NTNU* Norwegian University of Science and Technology, *VIMU* University Museum, *UiO* University of Oslo, *NHM* Natural History Museum, *UiB* University of Bergen, *UM* University Museum, *NBIC* Norwegian Biodiversity Information Centre, *NZF* Norwegian Zoological Organization, *gbif* the Global Biodiversity Information Facility

Table 3 Recordings of ichthyoplankton of *Arnoglossus laterna* recorded from IMR cruises and Citizen Science within Norwegian waters from 1991 to 2023. Columns include date, cruise, location, approximate latitude and longitude (DD), gear type, depth (m), amount, total length (mm), comments/ references

Date	Cruise	Location	Latitude	Longitude	Gear type	Depth	Amount	Total length	Comments/ references
14–16.11.1991	IMR cruise	Torungen-Hirtshals, Agder, trawl st. 84	58.2669	8.9833	MIK	405	1*		Hansen et al. (1992)
		trawl st. 85	58.2003	9.0833	MIK	417	2*		
		trawl st. 89	57.9336	9.4500	MIK	171	1*		
		trawl st. 92	57.7003	9.7833	MIK	62	2*		
		trawl st. 93	57.8503	9.5667	MIK	72	1*		
26–29.11.1991	IMR cruise	Torungen-Hirtshals, Agder, trawl st. 106	57.9669	9.6667	MIK	33	1*		Birkeland et al. (1992)
		trawl st. 108	57.9669	9.6667	MIK	34	1*		
4/22/1998	IMR cruise, 1998004	Selbjørnsfj, Austevoll	59.0000	5.1667	Vertical haul	75–0	1*	5	IMR database, st. 473
4/22/1998	IMR cruise, 1998004	Stord	59.0000	5.3167	Vertical haul	75–0	1*	4	IMR database, st. 474
4/22/1998	IMR cruise, 1998004	off Egersund	58.4167	5.5667	Vertical haul	150–0	1*	10	IMR database, st. 479
4/23/1998	IMR cruise, 1998004	off Flekkefjord	57.9167	6.3167	Vertical haul	75–0	1*	7	IMR database, st. 484
05.07.2011**	IMR cruise, 2011210	Adjacent to Ekofisk	57.0008	3.6623	MIK	57–0	1	7.08	
7/5/2011	IMR cruise, 2011210	Adjacent to Ekofisk	57.0008	3.6623	MIK	57–0	1	6.92	
7/5/2011	IMR cruise, 2011210	Adjacent to Ekofisk	57.0008	3.6623	MIK	57–0	1	7.69	
7/5/2011	IMR cruise, 2011210	Adjacent to Ekofisk	57.0008	3.6623	MIK	57–0	1	7.69	
7/5/2011	IMR cruise, 2011210	Adjacent to Ekofisk	57.0008	3.6623	MIK	57–0	1	5.23	
7/5/2011	IMR cruise, 2011210	Adjacent to Ekofisk	57.0008	3.6623	MIK	57–0	1	7.69	
7/5/2011	IMR cruise, 2011210	Adjacent to Ekofisk	57.0008	3.6623	MIK	57–0	1	6	
7/5/2011	IMR cruise, 2011210	Adjacent to Ekofisk	57.0008	3.6623	MIK	57–0	1	5.38	
6/21/2019	IMR cruise	Ekofisk Oil Field	56.5333	3.2000	WP plankton net		1		Mateos-Rivera et al. (2020), 1 egg recorded
		Stavanger					1		Larva following *Beroe* sp., uwphoto.no
8/26/2023	Sea Snack Norway, HR	Haganes, Sotra, Bergen	60.2761	5.1172	Dip net from shore	0.2	1	30	Larva measured by ruler. Larva following *Mnemiopsis leidyi*. DNA sequencing

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*ID to *Arnoglossus* sp

**During this cruise a total of 16 larvae were obtained, of which only 50% were length measured

217

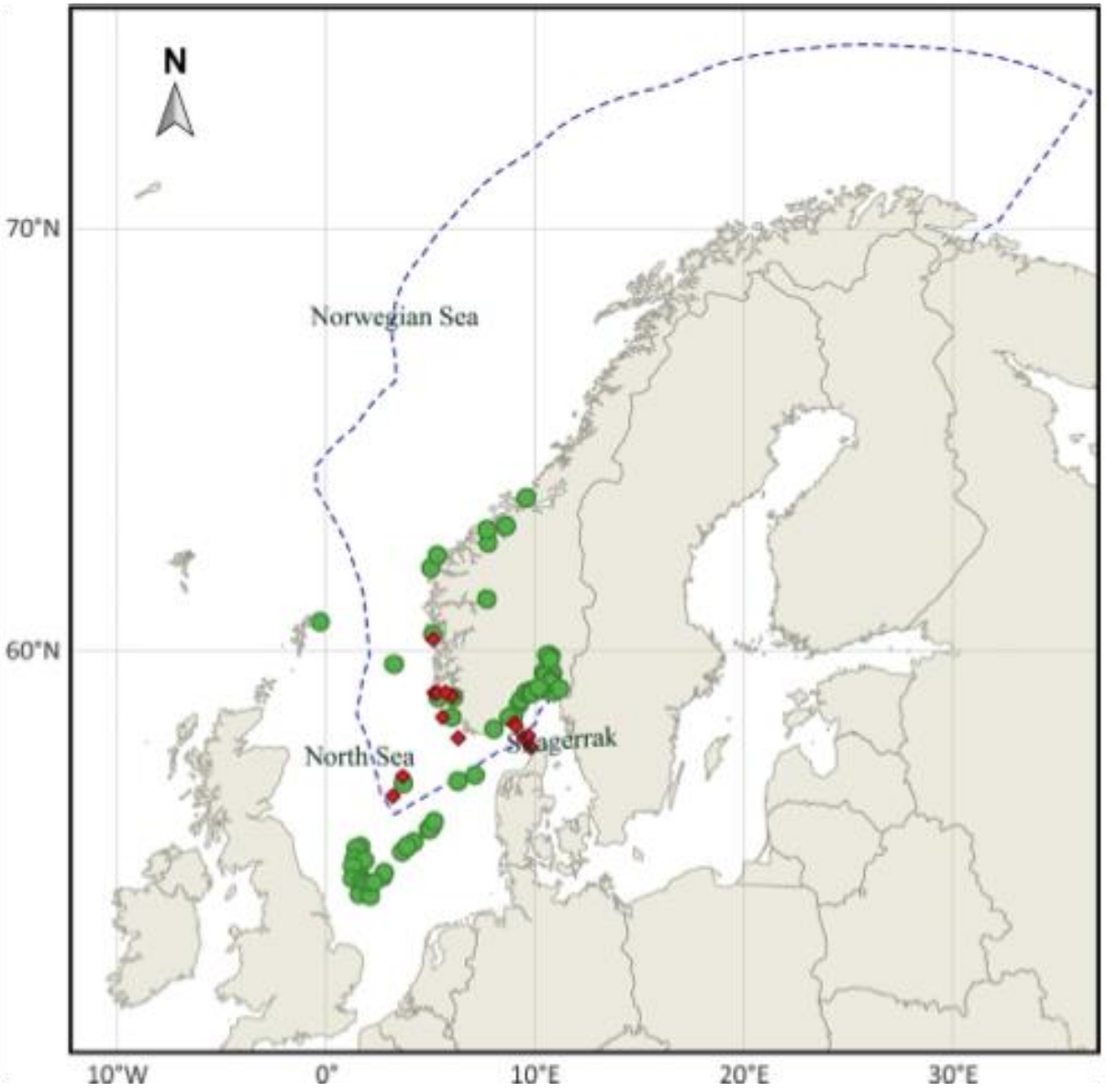
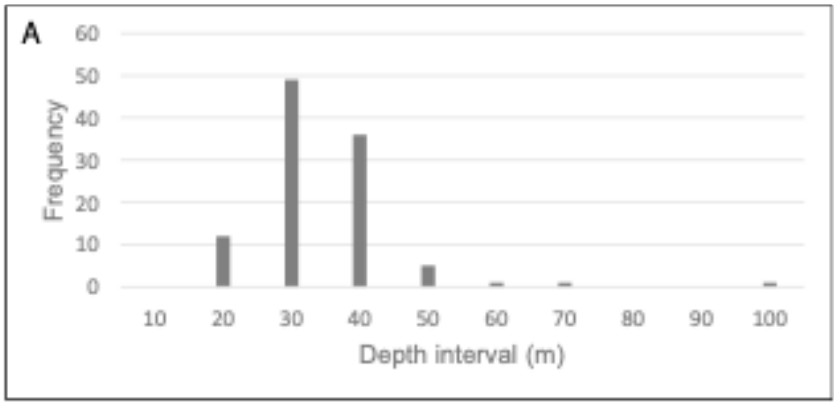
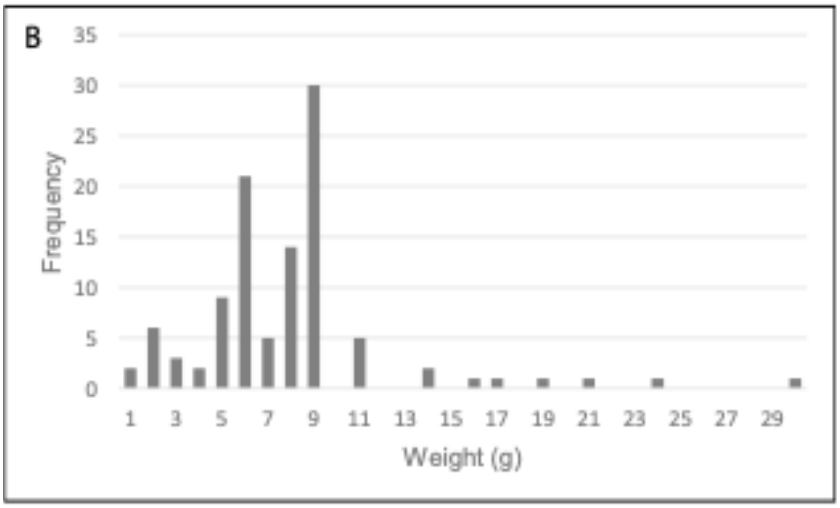


Fig. 1 Recordings of Arnoglossus laterna within Norwegian EEZ (dashed line), Skagerrak, and Central and Northern North Sea (Circles = adults and diamonds =larvae.). Map was made using Qgis Software (version 3.32).

Data from IMR cruises (2005-2022, Table 1 a), using benthic gear in shallow depths (<100 m), show frequency distributions of *A. laterna* per depth interval (in 10 m bands, Fig. 2a), per average individual weight (g, Fig. 2b) and per total length (cm, Fig. 2c). Highest encounters of specimens were found between 30-40 m depth which contrasts shallower observations further south in the North Sea (Sell and Kröncke 2013). Total weight distribution of specimens was from 1-30 g of which highest frequencies were between 6-9 g in wet weight. These results are in line with other shallow studies (<100 m depth) from e.g. Turkey and Scotland where Ilhan et al. (2010) reported a total weight distribution of all specimens between 0.47-41.63 g, of which highest

frequencies were between 7-10 cm in total length. Length distributions were from 1-15 cm of which highest frequencies were between 6-11 cm. Cicek et al. (2006) (also Turkey) reported a total length distribution between 2.2-11.8 cm. Accordingly, Gibson and Ezzi (1980) (Scotland) reported a total length distribution between 2.6-14.2 cm, and data from Denmark showed total length of *A. laterna* in the range of 3.5-12 cm at 4-6 m depth (Asmus et al. 2020).





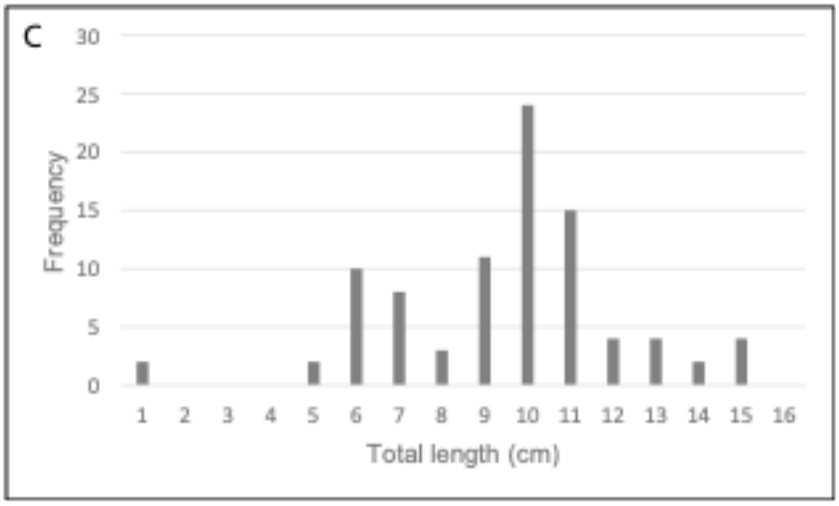


Fig. 2 Frequency distributions of Arnoglossus laterna from IMR cruises: a per depth interval (in 10 m bands), sts 43, n = 105; b per average individual wet weight (in g), sts 43, n = 105; c per total length (in cm), sts 42, n = 90. Figures were made using Microsoft Office Excel Software

University and Citizen Science data on *A. laterna* (Table 1 b) have been recorded from ~7–200 m depth, of which Universities account for the deepest sampling depths, is within previously reported depth range (10-400 m depth on the continental shelf) (Tous et al. 2014; Carpenter and Angelis 2016).The largest specimen from Arendal (verified by photo from www.dugnadforhavet.no by TM) measured 26.5 cm in length, and is probably the largest individual ever recorded. To our knowledge, previous maximum length was 25 cm (Muus and Nielsen 1999). Kögel et al. (2017) mentioned that *A. laterna* was consumed by locals in Årdalsfjorden (Sognefjorden, Norway), however, after talking to locals (Vidar Aasen, pers. comm.), this statement is most likely based on a misunderstanding.

Norwegian Citizen scientists also report on a few locations in Sandefjord and Kristiansand where they catch *A. laterna* on a regular basis (Table 1 b). After fish species hunter Espen A. Krogh from the Sandefjord/ Larvik area in 2010 regularly caught *A. laterna* using smaller baited hooks from his boat, he has since been fishing for them every now and then. Most specimens were caught between May to October (especially in June/ July) at around 5-12 m depth, measuring between 10-20 cm in length. Also a few specimens have been caught in March, but deeper (20-35 m depth). When walking along the shoreline with an aquascope in March/ April 3-4 specimens of *A. laterna* have been observed in shallow waters (around 1 m depth) within a 1-2 km^2 radius, burying in the sand and difficult to spot, so the actual abundance could be even higher (Espen A. Krogh, pers. comm.). This phenomenon could be due to spawning behaviour, and is similar to what is reported from Portugal where adult *A. laterna* is known to gather in high abundance in coastal areas during spring, possibly prior to the spawning event increasing condition (Cabral 2000).

Ichthyoplankton

Arnoglossus laterna is a spring and summer spawner (April-September) with only one annual spawning period (Deniel 1983; Nielsen 1986), and becomes sexual mature around two years of age when 6-9 cm in length (Scotland/ North Sea), and ~11 cm in length (Turkey) (Gibson and Ezzi 1980; Munk and Nielsen 2005; Ilkyaz et al. 2017), stages also present in our material (Fig. 2).

Egg and larvae were recorded offshore and inshore (coastal waters), indicating both areas as spawning- and nursery grounds within Norwegian EEZ. Inshore Norwegian waters has previously shown to be of importance as spawning and/ or nursery areas for early life stages of e.g. another flatfish, the Atlantic halibut *Hippoglossus hippoglossus* (Linneus, 1758), as well as the blackbelly rosefish *Helicolenus dactylopterus*

(Delaroche, 1809) (van der Meeren et al. 2013; Ringvold and Vesterinen 2021). Coastal areas in southern North Sea are spawning and nursery areas for *A. laterna* (van Hal et al. 2010; Macher et al. 2020). In the Tagus and Sado estuaries in Portugal, occurrence of juveniles indicate that these estuaries represent important nursery areas. *A. laterna* is frequently encountered from both estuaries, and for Sado, which is less than 10 m deep and dominated by mud and sand, it thrives only in the outer part of the estuary (Cabral 2000; Prista et al. 2003).

Eggs of *A. laterna* measure 0.60-0.76 mm in diameter, have unsegmented yolk and one oil globule (0.11-0.15 mm in diameter) (Munk and Nielsen 2005). One egg has been collected 21 June 2019 in central North Sea at Ekofisk Oil field (~56.3ºN) (Mateos-Rivera et al. 2020) (Table 1 c). In another study from southern North Sea where sampling was conducted from March to August, *A. laterna* eggs were most abundant in May, but also with some occurrence in June and July (van der Land 1990). Seasonal ichthyoplankton studies from Turkey show that eggs of *Arnoglossus* sp. are found all year round (Hossucu and Ak 2002).

Ichthyoplankton of *A. laterna* in Norwegian EEZ was observed from April to November (measuring from 3 to 7.69 mm in length, Table 1 c), including 16 larvae recorded near Ekofisk Oil Field (5 July 2011). A study from southern North Sea shows 0-group *A. laterna* present during weeks 24-33 [June-August], with a peak during week 26-33 (Greve et al. 2005). In England (Plymouth) post-larvae of *A. laterna* were recorded from June to October with a peak in August-September (Russell 1935). From Turkey, larvae of *Arnoglossus* sp. and *A. laterna* are obtained during spring only (Hossucu and Ak 2002).

During flexion stage the eyes are still on each side of the head, and one large fin ray is present above the head (Munk and Nielsen 2005). On the Haganes-larva, both blue and yellow bioluminescent spots were observed, especially visible in two bands on the dorsal- and ventral fins (Fig. 3). These spots are probably caused by bacteria *Vibrio gigantis* Le Roux, Goubet, Thompson, Faury, Gay, Swings & Saulnier, 2005 and *V. crassostreae* Faury, Saulnier, Thompson, Gay, Swings & Roux, 2004, two bioluminescent strains extracted from *A. laterna* (Ersoy Omeroglu 2015). Similar yellow and blue bioluminescence is seen on larvae of *A. yamanakai* Fukui, Yamada & Ozawa, 1988 (Minemizu 2017).

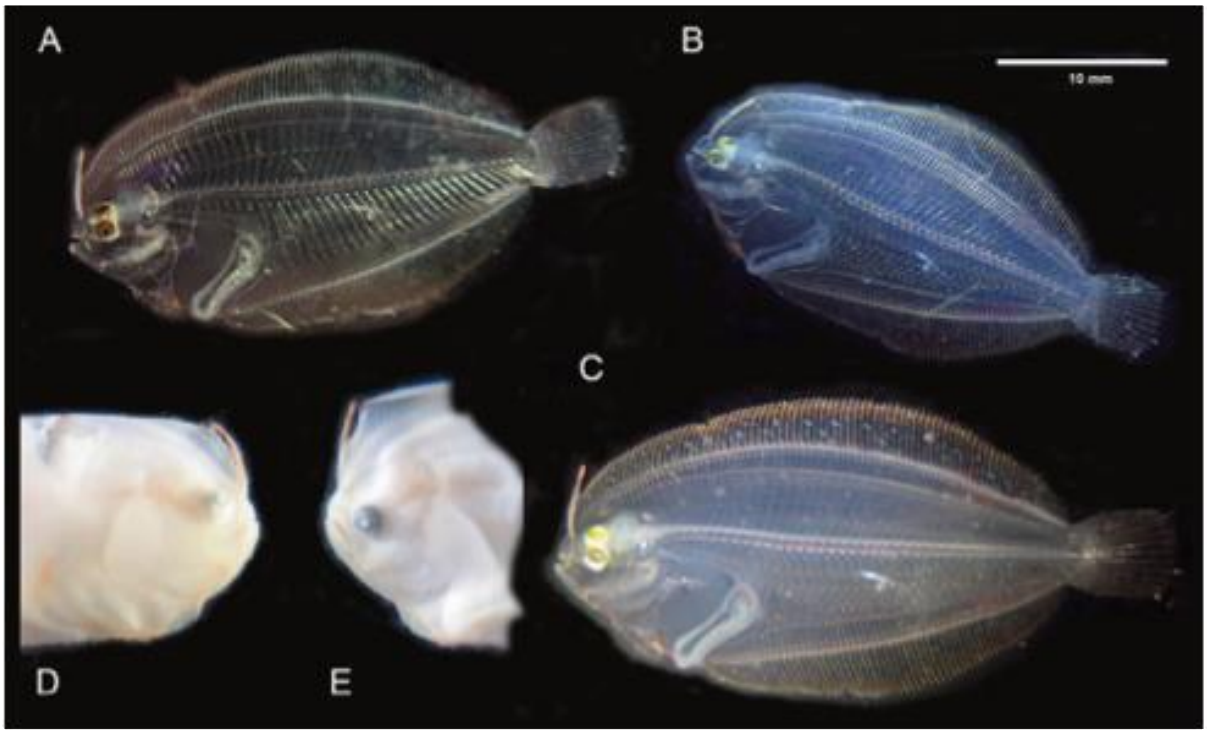


Fig. 3 A–C Live larva of Arnoglossus laterna collected at Haganes (Bergen) 26 August 2023 at about 20 cm depth, identified using morphologcial and molecular methods. In B and C bands with yellow and blue bioluminescent bacteria on the dorsal and ventral fins are visible. D and E show the same specimen as in A–C, but preserved (Photo: Halldis Ringvold/ Sea Snack Norway)

The Haganes-larva

In our molecular analysis, *when* comparing the 16S sequence from Haganes-larva to all sequences in nucleotide database in GenBank using online BLAST, our sequence showed 99.33 % identity (percentage of identical nucleotides between the query sequence and the reference sequence) with *Arnoglossus laterna* (MN122822.1; Denmark) with 100% query coverage (the percentage of the query sequence that the alignment covers with the reference sequence). The second match was to *A. laterna* (KJ128705.1; Sweden) with 99.66 % identity and 97% coverage. BLAST results from COI sequence (from Haganes-larva) in Genbank also showed 100% identity to *A. laterna* (KM538213.1; Mediterranean), with 100% query coverage. Subsequent second and thirds matches were to *A. laterna* (MN122822.1; Denmark and KJ205272.1; North Sea), both with 99.85% identity and 100% coverage. Comparison to BOLD database using COI sequence (from Haganes-larva) resulted 100% match with a

322 public record of an adult *A. laterna* from Oslofjord, Råde, collected in 2009 (NOFIS055-10). The assembled
323 sequences produced in this study have been stored into GenBank with accession codes PQ533213 (COI) and
324 PQ533227 (16S)

325

326 The *A. laterna* larva observed in Bergen area (Haganes) was transparent, except for the eyes which were black/
327 opaque. The larva was observed *in situ* (by author HR), and swimming vertically close to the ctenophore
328 *Mnemiopsis leidyi*, probably hiding from predators. The larva was caught at about 20 cm depth, above a ~3 m
329 water column, at a boat pier. The water temperature was ~17 ºC. The observation was conducted during a
330 zooplankton bloom, consisting of *Pleurobrachia pileus* (O. F. Müller, 1776), *Leucartiara octona* (Fleming,
331 1823), larvae of *Luidia sarsii* Düben & Koren, 1844, *Tomopteris* sp., and various copepod species. Another *A.*
332 *laterna* larva (from Stavanger area, Table 1 c), observed *in situ,* was also swimming close to a ctenophore (*Beroe*
333 sp.). Interactions between fish and jellyfish are well known, especially adapted as an anti-predator strategy for
334 fish larvae of benthic fish species, where jellyfish provides habitat and protects them from predators (Russell
335 1935; Griffin et al. 2019). However, jellyfish are also known to compete with fish for food or feed on fish eggs
336 and larvae, thus with the potential to affect fish recruitment. An example may be the medusa *Pelagia noctiluca*
337 (Forsskål, 1775) in the Mediterranean region, known to feed on larvae of *A. laterna* (Tilves Matheu 2019).

338 Although most *A. laterna* larvae within the Norwegian EEZ was recorded >30 m depth, the larva from
339 Haganes pier, Bergen was recorded from shallow inshore coastal waters. In comparison, 0-group of *A. laterna*
340 larvae from nearby Wadden Sea (Southern North Sea) were only found in open offshore waters deeper than
341 about 15 m (between 15-70 m, with a peak about 35 m) (Baltus and van der Veer 1995). A study on vertical
342 distribution of shelf-dwelling species from the NW Mediterranean Sea showed larvae of *Arnoglossus sp.* had a
343 broad distribution within the upper 40 m, while most other larvae were present in the upper 10 m of the water
344 column (Olivar and Sabatés 1997).

345 The larva from Haganes was observed during mid-day. Other studies (from Mediterranean Sea and
346 Celtic Sea, respectively) report on a tendency of *Arnoglossus* sp. larvae to concentrate at greater depth (~30 m) at
347 night rather than during the day (Röpke 1989; Olivar and Sabatés 1997).

The Hagenes larva measured 30 mm in length and was the largest larva in our study. However, it had not gone through metamorphosis. Temperature and food availability may impact growth and timing of metamorphosis, as discussed in Sardi et al. (2023). Also, metamorphosis in *A. laterna* larvae may be delayed depending on the depth of water under the larva, resulting in onset of metamorphosis at different lengths (Kyle 1913). This results in variation in size and number of vertebrae at which bottom settling occurs, from 16-30 mm overall, with the largest found in Bay of Biscay. The depth-related variation in number of vertebrae and length at metamorphosis can even be seen within the North Sea, from south to north (Kyle 1913). In comparison, Atlantic halibut *Hippoglossus hippoglossus* settle between 34-40 mm (Haug 1990).

In relation to ocean warming there is an increasing trend in numbers of warm-favouring (Lusitanian) species, as e.g. *A. laterna*, expanding into Greater North Sea region (Anonymous, EEA 2022). Having already reached Mid-Norway, *A. laterna* might also be able to extend its habitat even further north.

Conclusion

This study from the northernmost distribution of *A. laterna* shows, by using a pool of both published and unpublished sources (1876 to 2023), that this species is recorded north to the Trondheimsfjord in Norway. One specimen from Arendal measured 26.5 cm in length, and is probably the largest individual ever recorded. Both offshore and inshore waters are identified as possible spawning- and nursery grounds since both egg and larvae have been recorded offshore, and larvae have been recorded inshore. Inshore, a larva was recorded as shallow as 20 cm deep below surface (Haganes larva), following ctenophores, probably hiding from predators. An expansion of the species further northwards is expected due to climate change with increasing sea water temperatures.

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Figure legends

Fig. 1 Recordings of *Arnoglossus laterna* within Norwegian EEZ (dashed line), Skagerrak, and Central and Northern North Sea. (Circles=adults and diamonds=larvae.). Map was made using Qgis Software (version 3.32).

Fig. 2 Frequency distributions of *Arnoglossus laterna* from IMR cruises: **a)** per depth interval (in 10 m bands), sts 43, n=105. **b)** per average individual wet weight (in g), sts 43, n=105. **c)** per total length (in cm), sts 42, n=90. Figures were made using Microsoft Office Excel Software.

Fig. 3 a-c Live larva of *Arnoglossus laterna* collected at Haganes (Bergen) 26 August 2023 at about 20 cm depth, identified using morphologcial and molecular methods. In b and c bands with yellow and blue bioluminescent bacteria on the dorsal and ventral fins are visible. **3 d-e** show same specimen as in 3 a-c, but preserved (Photo: Halldis Ringvold/ Sea Snack Norway).

Table 1

Recordings of *Arnoglossus laterna*, mainly within Norwegian waters, from 1876-2023. **a)** Adults recorded mainly from IMR cruises during 1994-2022. Columns include date, type of cruise, approximate latitude and longitude (DD, at start of haul), gear type, depth (m, at start of haul), amount, total wet weight of all specimens at the station (kg) and comments/ references. **b)** Adults recorded by Universities/ institutions and Citizen Science, from 1876 to 2023. Columns include institution, observer, observation date and location, amount, approximate latitude and longitude, gear types, depth (m), comments, references. **c)** Ichthyoplankton recorded from IMR cruises and Citizen Science. Columns include date, cruise, location, approximate latitude and longitude (DD), gear type, depth (m), amount, total length (mm), comments/ references. For all tables: Institute of Marine Research (IMR); Norwegian University of Science and Technology (NTNU), University Museum

(VIMU); University of Oslo (UiO), Natural History Museum (NHM); University of Bergen (UiB), University Museum (UM); Norwegian Biodiversity Information Centre (NBIC); Norwegian Zoological Organization (NZF); the Global Biodiversity Information Facility (gbif).

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Competing interests

The authors declare that they have no conflict of interest.

Ethical approval

No animal testing was performed during this study.

Sampling and field studies

All necessary permits for sampling and observational field studies have been obtained by the authors from the competent authorities and are mentioned in the acknowledgements, if applicable.

Data availability

All data that support the findings of this study are included within this paper.

Author Contribution Statement

HR Conceptualized, collected and analyzed data, made map, table, figures and photos, and wrote the manuscript. TM identified several specimens, contributed on the map, and read and approved the manuscript. EV and EM conducted genetic analysis, and read and approved the manuscript.

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