



Diversity of Caudofoveata (Mollusca) around Iceland and description of *Psilodens balduri* sp. n.

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Abstract: The first records from samples from the IceAGE cruise ME85/3 in 2011 include seven species of Caudofoveata with a distribution range in Icelandic waters. From this first cruise of the project, two new records for Iceland have been registered. *Psilodens balduri* sp. n. is new to science and *Falcidens halanychi*, with a known distribution in the American North-Atlantic, is new to Iceland. The current study thus increases the number of known caudofoveate species around Iceland to nine.

Key words: Icelandic waters, Aplacophora, Chaetodermomorpha, *Psilodens*, taxonomy, biogeography.

Introduction

The shell-less, worm-shaped Caudofoveata have received a relatively large amount of attention in the North Atlantic, compared to other areas (Heath 1911, 1918; Salvini-Plawen 1975; Scheltema 1985; Scheltema and Ivanov 2000), but few records of this aplacophoran mollusc taxon exist from Icelandic waters. Iceland is uniquely situated in the center of the North Atlantic, in connection with the Greenland-Iceland Ridge in the west, and the Iceland-Faroe Ridge in the southeast. These ridges strongly influence regional ocean currents, in turn influencing water temperature and faunal communities. This location is the reason for a caudofoveate fauna consisting of species with distributions in both the western and eastern side of the Atlantic, resulting in relatively high species diversity. Until now, seven species of Caudofoveata have been registered in the material sampled, representing all three recognized families in the group (see Table 1). Except for *Chaetoderma nitidulum* Lovén, 1844 (Salvini-Plawen 1975), all published records of Caudofoveata from Iceland are restricted to the south and southwestern side of

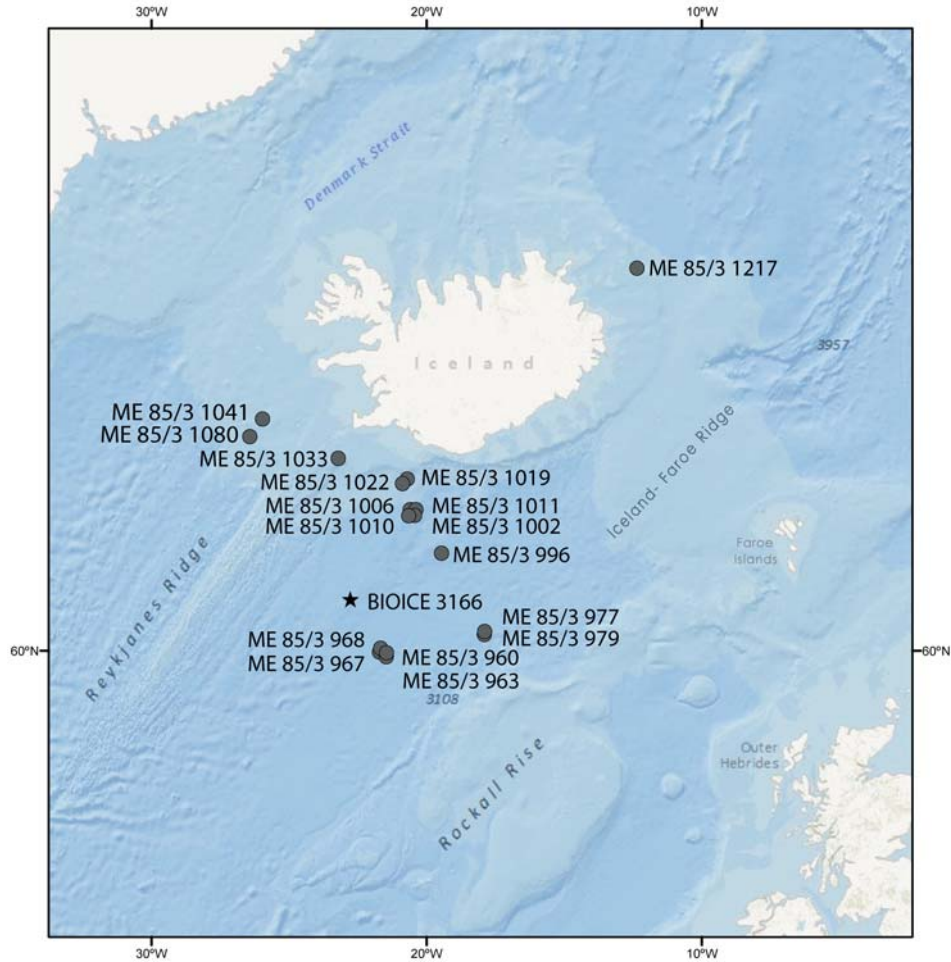


Fig. 1. Stations from which species of Caudofoveata have been registered from the IceAGE ME85/3 cruise (for species list, see Table 1). Asterisk indicates the BIOICE station from which *Psilodens balduri* sp. n. was sampled.

Iceland. The majority of published records stem from caudofoveates sampled during the BIOICE project between 1992 and 1997 (Ivanov and Scheltema 2001). Here we present data from the first cruise of the IceAGE project, and summarize the current knowledge on the distribution of Caudofoveata in Icelandic waters.

Materials and methods

From the material that has been sorted to date from the IceAGE1 cruise with R/V *Meteor* in 2011, 60 specimens of caudofoveates from 19 stations were available for investigation (Fig. 1, Table 1). Sampling was conducted with epibenthic

Table 1
Species of Caudofoveata sampled during the ME85/3 IceAGE cruise (see also Fig. 1).

Station	Date	Gear	Position (lat, long)	Depth (m)	Species
960	2011-08-28	box corer	60°2.73' N, 21°30.14' W	2750	<i>Falcidens halanychi</i> , <i>Spathoderma alleni</i> , <i>Spathoderma clenchi</i>
963	2011-08-28	epibenthic sled	60°2.72' N, 21°29.52' W – 60°2.73' N, 21°29.86' W	2746	<i>Falcidens halanychi</i> , <i>Spathoderma clenchi</i> , <i>Psilodens balduri</i> sp. n.
967	2011-08-29	epibenthic sled	60°2.78' N, 21°29.78' W – 60°2.78' N, 21°30.07' W	2746–2749	<i>Falcidens halanychi</i>
968	2011-08-29	Agassiz trawl	60°2.73' N, 21°34.61' W – 60°2.73' N, 21°35.57' W	2728–2731	<i>Psilodens balduri</i> sp. n.
977	2011-08-30	box corer	60°20.54' N, 18°8.69' W	2572	<i>Spathoderma clenchi</i>
979	2011-08-30	epibenthic sled	60°20.87' N, 18°8.52' W – 60°20.72' N, 18°8.60' W	2569–2571	<i>Spathoderma clenchi</i>
996	2011-09-01	box corer	61°42.49' N, 19°32.78' W	1913	<i>Spathoderma clenchi</i>
1002	2011-09-02	box corer	62°33.50' N, 20°21.18' W	1392	<i>Prochaetoderma yongei</i>
1006	2011-09-02	epibenthic sled	62°33.23' N, 20°22.52' W – 62°33.29' N, 20°22.21' W	1389	<i>Prochaetoderma yongei</i>
1010	2011-09-02	epibenthic sled	62°33.17' N, 20°23.18' W – 62°33.22' N, 20°22.88' W	1383–1388	<i>Prochaetoderma yongei</i>
1011	2011-09-03	Agassiz trawl	62°33.35' N, 20°22.50' W – 62°33.47' N, 20°21.54' W	1389–1390	<i>Falcidens sagittiferus</i>
1019	2011-09-03	epibenthic sled	62°56.32' N, 20°44.61' W – 62°56.46' N, 20°44.06' W	914–916	<i>Prochaetoderma yongei</i>
1022	2011-09-03	box corer	62°55.58' N, 20°47.36' W	907	<i>Falcidens sagittiferus</i> , <i>Prochaetoderma yongei</i>
1033	2011-09-04	epibenthic sled	63°18.97' N, 23°9.64' W – 63°19.12' N, 23°9.69' W	291–294	<i>Spathoderma alleni</i>
1041	2011-09-05	epibenthic sled	63°55.36' N, 25°57.85' W	215	<i>Falcidens sagittiferus</i>
1080	2011-09-09	box corer	63°41.90' N, 26°24.44' W	714	<i>Prochaetoderma yongei</i>
1217	2011-09-22	box corer	66°32.48' N, 12°52.21' W	315	<i>Chaetoderma nitidulum</i>

sleds, box corer and Agassiz trawl, and samples were fixed in formalin or 96% ethanol after sieving. To ensure the quality of fixation of specimens for molecular studies, an unbroken cold chain was maintained for samples for fixation in ethanol: the samples were sieved at 4°C and subsequently stored at -20°C, and all sorting of ethanol fixed material was done on ice. Material of *Psilodens balduri* sp. n. sampled during the BIOICE project in 2000 was included in this study.

Radula and sclerites were investigated using standard techniques for the group (Ivanov *et al.* 2009). The radula was dissected out, and the surrounding tissue dissolved in sodium hypochlorite (bleach). The radula was rinsed in distilled water before permanent mounting in a drop of glycerin on a slide. Pieces of cuticle were cut from the different body regions and dissolved, the sclerites were shaken off into distilled water on a slide, and left to dry before mounting in araldite epoxy resin (Huntsman Advanced Materials) and polymerized overnight at 70°C.

DNA was extracted from specimens of each of the species that were present in the samples fixed in ethanol using the Qiagen Blood and Tissue Kit, following the manufacturer's instructions in the tissue protocol. PCR amplification and sequencing of a ~650 base pair long fragment of the COI (cytochrome c oxidase 1) gene was performed using the universal COI primers HCO2198/ LCO1490 (Folmer *et al.* 1994). PCR amplification was performed with an initial step of 94°C for 5 min followed by 35 cycles of 94°C for 30 sec, 50°C for 30 sec and 72°C for 1 min, and final elongation step at 72°C for 5 min. The PCR products were purified using ExoSAP-IT (Affymetrix), and sequenced using an ABI 3700 DNA Sequencer (Applied Biosystems).

Where possible, analyses of COI sequences from species with distributions extending beyond Icelandic waters included sequences from specimens from other parts of the distribution range. This was done in order to confirm the identity of the specimens from Iceland with conspecifics from other parts of the distribution range.

Results

The material from the IceAGE cruise in 2011 contained specimens of six of the seven species previously known from Icelandic waters (see Table 1). In addition, we have found one species of *Falcidens* Salvini-Plawen, 1968 new to Iceland (*F. halanychi* Schander, Scheltema *et* Ivanov, 2006) and a species of *Psilodens* Salvini-Plawen, 1977 new to science.

Systematics and biogeography

Caudofoveata Boettger, 1955

Synonym: Chaetodermomorpha Pelseneer, 190

Family Chaetodermatidae Ihering, 1876

Chaetoderma nitidulum Lovén, 1844

This species has a previously reported distribution in the eastern Atlantic from the British Isles in the south to the Svalbard archipelago in the north (Salvini-Plawen 1975, 1978). In the present material, *Ch. nitidulum* has only been recorded from the northeastern side of Iceland, and it is the only species of Caudofoveata in Icelandic waters registered from north of the Iceland-Faroe Ridge (Fig. 1).

Falcidens sagittiferus Salvini-Plawen, 1968

This species has a distribution from Iceland in the west extending to the Norwegian coast in the east (Salvini-Plawen 1975; Ivanov *et al.* 2009). All Icelandic

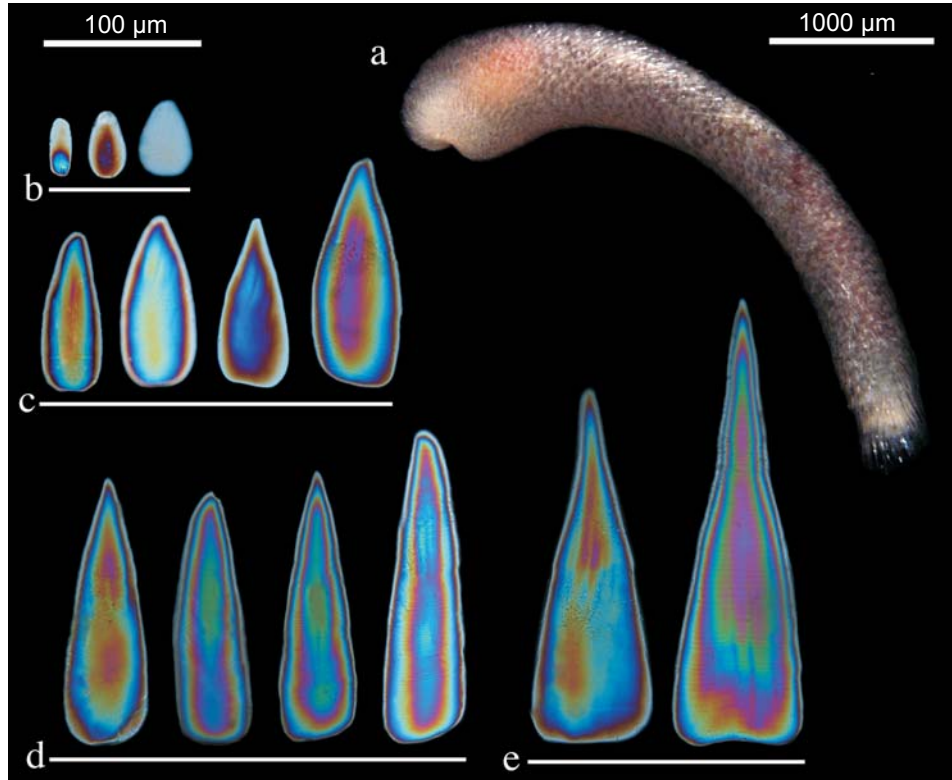


Fig. 2. *Falcidens halanychi*: **a**, specimen from ME85/3 St 967; **b–e**, sclerites photographed under cross-polarized light: anterium (**b**), neck (**c**), anterior trunk (**d**), posterior trunk (**e**).

records of *F. sagittiferus* are from the southern side of Iceland, a distribution that is restricted to more southern latitudes compared to the distribution along the Norwegian coast (Ivanov and Scheltema 2001; Ivanov *et al.* 2009).

Falcidens halanychi Schander, Scheltema *et* Ivanov, 2006

(Fig. 2)

This species has previously been reported from the north east American coast south to Cape Hatteras between latitudes 38°34' N and 39°48' N in 1102–2886 m depth (Schander *et al.* 2006). *F. halanychi* has not previously been reported from Iceland. In the present samples it has been found southeast of Iceland between the Reykjanes Ridge and the Iceland-Faroe Ridge from depths 2746–2750 m. These new records give this species a distribution extending from Iceland to the North American coast.

In addition to these species, *F. thorensis* Salvini-Plawen, 1971, has been reported from Iceland (Ivanov and Scheltema 2001) but it has not yet been found in the samples from IceAGE ME85/3.

Family Prochaetodermatidae Salvini-Plawen, 1975

Prochaetoderma yongei Scheltema, 1985*Spathoderma clenchi* Scheltema, 1985*Spathoderma alleni* Scheltema et Ivanov, 2000

Remarks. — All three species of Prochaetodermatidae previously reported from Iceland have been found in the samples from IceAGE cruise. *P. yongei* and *S. clenchi* are both amphi-Atlantic species, while *S. alleni* has been recorded from Iceland, and from the West European Basin to the Mediterranean.

Family Limifossoridae Salvini-Plawen, 1970

Scutopus robustus Salvini-Plawen, 1970

Remarks. — *S. robustus* is the only species of Limifossoridae reported from Icelandic waters (Ivanov and Scheltema 2001), but this species has not been found in the present material.

Psilodens Salvini-Plawen, 1977

Type species. — *Limifossor elongatus* Salvini-Plawen, 1972.

Diagnosis. — Radula distichous, lacking median denticles. Teeth smooth, singular. Radula bolsters paired. Habitus attenuated, slender. Oral shield paired, divided.

In addition to the species listed above, a new species of *Psilodens* Salvini-Plawen, 1977, was found in the material (see below). There are no previously published records of *Psilodens* from as far north as Iceland.

Psilodens balduri sp. n.

Type material. — Holotype: BIOICE Station 3166; measurements: length 27 mm, anterium 0.5 mm, neck 1.3 mm, anterior trunk 5.8 mm, posterior trunk 18.5 mm, posterium 1 mm; material: microscope preparation of sclerites; deposition: 1 ethanol fixed specimen and microscope preparation of sclerites have been deposited at the Icelandic Museum of Natural History under catalogue number 28850. Paratypes: paratype 1, IceAGE ME85/3 Station 963; measurements: length 9.1 mm, anterium 0.5 mm, neck 0.7 mm, anterior trunk 1.2 mm, 5.9 mm, posterium 0.8 mm; material: microscope preparations of radula and sclerites; deposition: 1 ethanol fixed specimen and preparations of radula and sclerites have been deposited at the Icelandic Museum of Natural History under catalogue number 28851. Paratype 2: IceAGE ME85/3 Station 968; incomplete specimen lacking posterior end; measurements: anterium 0.3 mm, neck 0.7 mm; material: microscope preparation of radula; voucher for DNA extraction (see below); deposition: 1 ethanol fixed specimen and microscope preparation of radula have been deposited at the University Museum of Bergen, Norway under catalogue number ZMBN 95457. Paratype 3: IceAGE ME85/3 Station 963; measurements: length 14.5 mm, anterium 0.3 mm, neck 1.3 mm, anterior trunk 2.5 mm, posterior trunk 10.1 mm, posterium 0.4 mm; material: microscope preparation of radula and sclerites. Voucher for DNA extraction

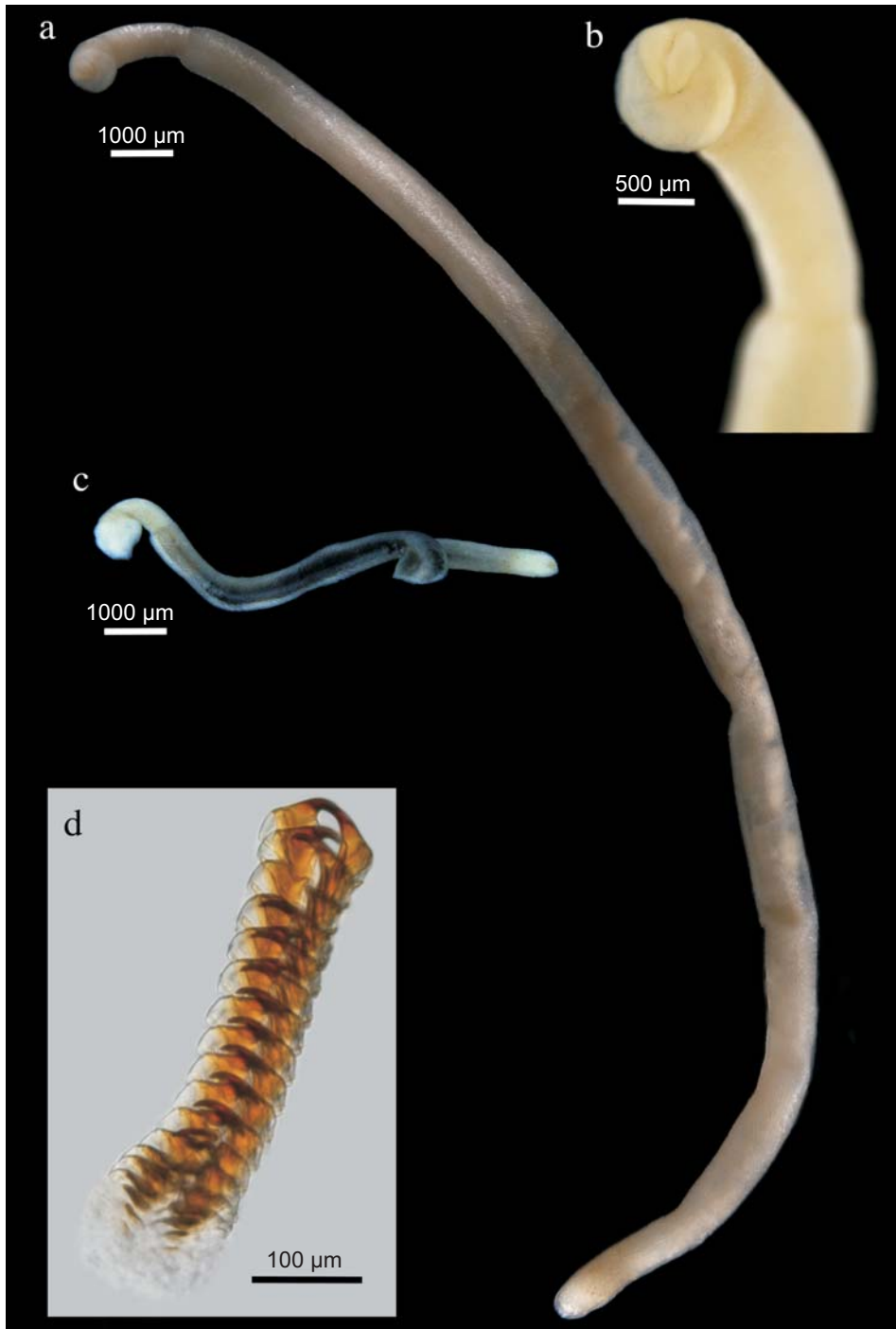


Fig. 3. *Psilodens balduri* sp. n.: holotype (a), oral shield of holotype (b), paratype 1 (c), radula from paratype 2 (d).

(see below); deposition: 1 ethanol fixed specimen and microscope preparations of radula and sclerites have been deposited at the University Museum of Bergen, Norway under catalogue number ZMBN 95458. Paratype 4: IceAGE ME85/3 Station 963; measurements: Length 5.1 mm, anterium 0.2 mm, neck 0.7 mm, anterior trunk 0.5 mm, 2.4 mm, posterium 0.3 mm; deposition: 1 ethanol fixed specimen has been deposited at the University Museum of Bergen, Norway under catalogue number ZMBN 95459.

Type locality. — Southwest of Iceland, BIOICE Station 3166, 60° 54' 57" N, 22° 47' 14" W to 60° 55' 14" N, 22° 46' 55" W, depth 1898–1900 m.

Material examined. — In total, six specimens were examined. In addition to the type specimens, one specimen from the same sample as the paratype, IceAGE ME85/3 St 963, was studied.

Etymology. — Named after the Norse god Baldr (or Baldur).

Description. — Habitus (Fig. 3): Body elongate, slender. Without clearly defined regions, except for anterior-most (“head”) region, which is clearly set apart by a slight constriction. Anterium and neck of narrower diameter than trunk. Anterior trunk with mid-ventral line (mantle suture). Posterium slightly tapered. Mouth between anterior third of pored oral shield. Dorso-terminal sense organ elongate above posterior-most mantle cavity. Body length up to 27 mm.

Sclerites (Fig. 4; greatest dimensions, length × width) broad, flat, asymmetrical, with a median ridge with a narrow central groove, faint chevron-shaped striations. Distal end slightly pointed, bases drawn out to a skewed triangle. Anterium: sclerites leaf-shaped scales, thin, flat, sclerites with rounded tip in the anterior end, more pointed further back, towards neck (50 × 20 µm). Neck: sclerites narrow scales, tip blunt (50 × 20 µm) to very slender, elongate with straight sides (67 × 15 µm). Anterior trunk: scales broader, leaf-shaped, with chevrons (95 × 30 µm). Posterior trunk: scales broad, leaf-shaped, with chevrons, tip blunt (110 × 45 µm). Posterium, around pallial cavity: curved sclerites, with broad, high keel extending almost to proximal end, asymmetrical (172 × 25 µm). Sclerites around dorso-terminal sense organ small, elongate, rounded (70 × 10 µm).

Radula (Figs 3 and 5): distichous, with about 18 pairs of teeth (3 specimens investigated; paratypes 1, 2 and 3). Total length 440 µm. Radula teeth with broad base and smooth medially curved tip, only tip of teeth sclerotized (Fig. 3d). Width of radula teeth 80 µm.

Oral shield (Fig. 3): divided and paired, the two halves slightly triangular. Mouth opening between anterior third of halves. Size of oral shield on holotype 420 × 420 µm (height × width) (Fig. 3b).

Distribution. — So far, the species has only been recorded from south west of Iceland from depths between 1898 m and 2746 m.

Taxonomic remarks. — The genus *Psilodens* contained until now only two described species; *Psilodens elongatus* (Salvini-Plawen, 1972), from off the Pa-

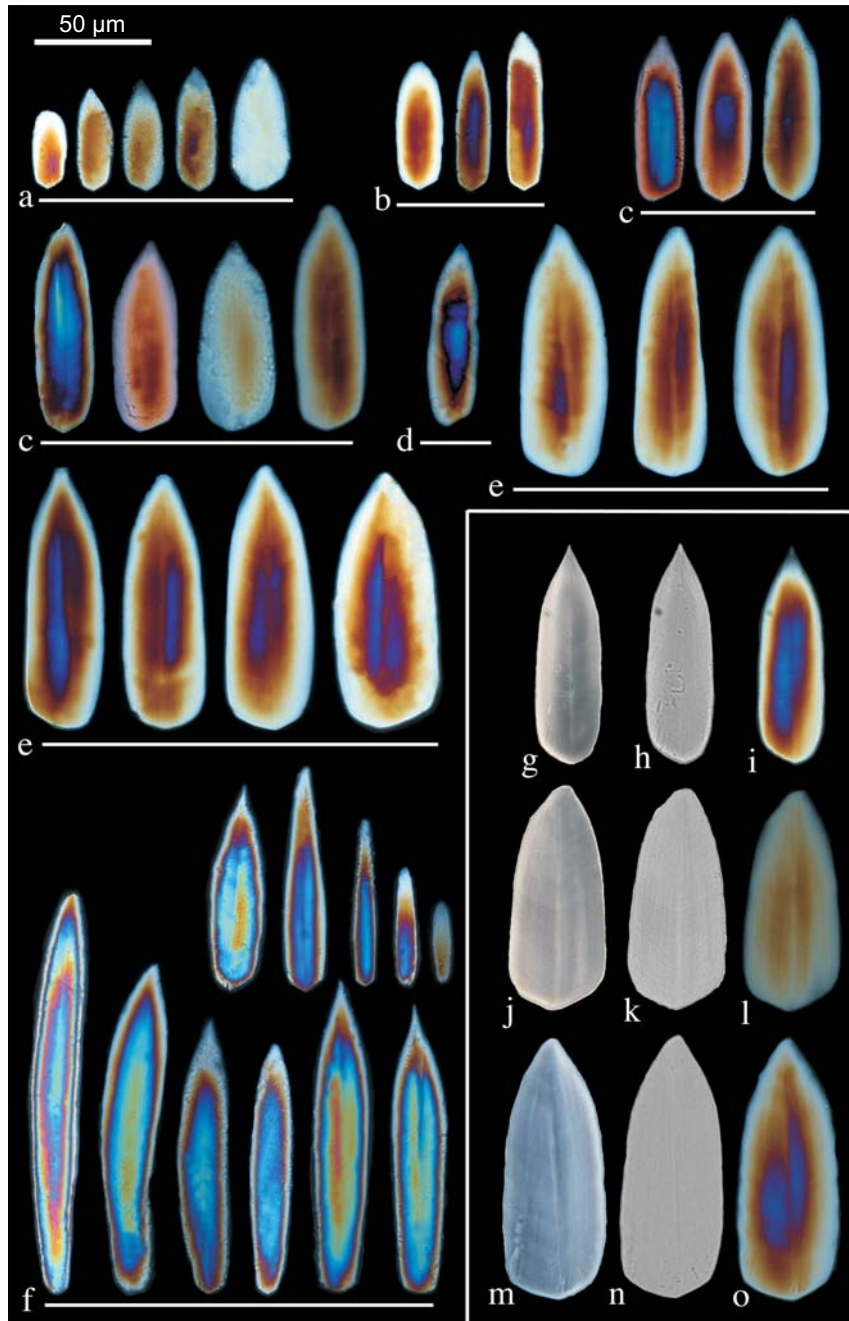


Fig. 4. *Psilodens balduri* sp. n. Sclerites from paratype 1 from ME85/3 St 963; **a–e**, photographed under cross-polarized light: anterior trunk (**a**), neck (**b**), anterior trunk (**c**), mid-ventral groove (**d**), posterior trunk (**e**), posterior (**f**); **g–o**, sclerites as seen under three different optical illumination techniques: phase contrast (**g**, **j**, **m**), brightfield (**h**, **k**, **n**), cross-polarized light (**i**, **l**, **o**), sclerite from anterior trunk (**g–i**), sclerites from posterior trunk (**j–o**).

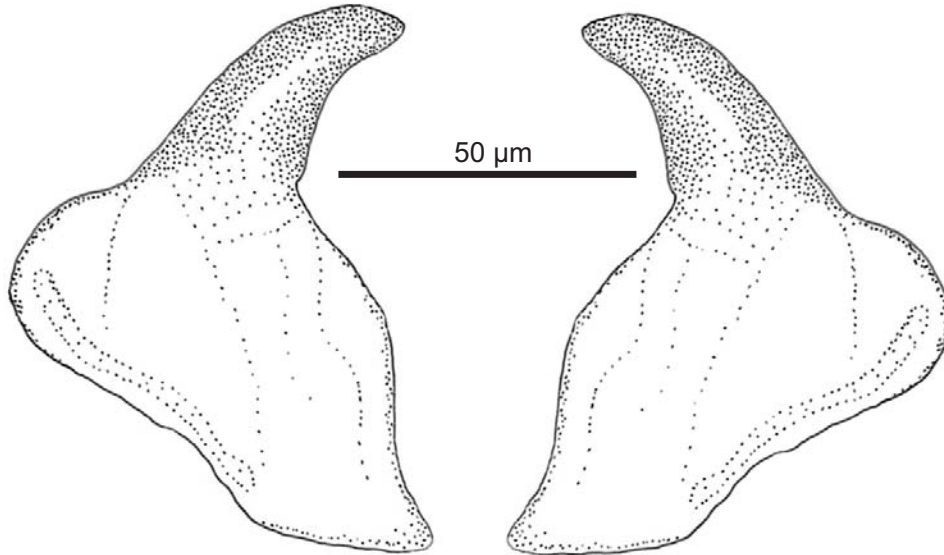


Fig. 5. *Psilodens balduri* sp. n., pair of radula teeth from paratype 2 from ME85/3 St. 968 (see also Fig. 3d).

cific Coast of central America, and *Psilodens tenuis* Salvini-Plawen, 1977, from the Strait of Gibraltar. *Psilodens balduri* sp. n. is differentiated from both *P. elongatus* and *P. tenuis* by the habitus and by the shape of the radula teeth and sclerites. *Psilodens balduri* has a clearly distinguished anteriormost (head) region and a ventral suture line, whereas *P. elongatus* and *P. tenuis* both have more uniform bodyshape, and lack a ventral line. The location of the mouth in respect to the oral shield also differs in *P. elongatus* and *P. tenuis* as compared to *P. balduri*: the oral shield halves in *P. tenuis* are behind the mouth, while in *P. elongatus* the mouth is in between their half extension. The teeth of the radula in *P. elongatus* are sickle-shaped, narrow and pointed, while in the two Atlantic species the teeth have a broader base and less pointed tips, but these species differ in the shape of the base of the teeth, which is broader and more pronounced in *P. balduri*. The three species are also distinguished by the sclerites; *P. elongatus* has drop-shaped sclerites with a pointed tip, clearly distinct from the two Atlantic species that have sclerites that are less pointed and have differently shaped bases. *Psilodens tenuis* has sclerites without keel that are tapering to a blunt tip, and have a flat base, while the sclerites in *P. balduri* are clearly distinguished by being more pointed, with a clear central elevation with a narrow groove and bases drawn out into a triangular shape.

Barcoding. — Sequences of the COI gene from two paratypes of *Psilodens balduri* sp. n. are deposited in GenBank under accession numbers HG975082 and HG975083.

Molecular identification. — COI sequences from *Ch. nitidulum* and *F. halanychi* from Iceland were compared to sequences from specimens from the Svalbard archipelago and northern Norway, and from Cape Hatteras, respectively. The uncorrected p-distance between the sequences within *Ch. nitidulum* was less than 0.1%, and between sequences from specimens of *F. halanychi* from Iceland and Cape Hatteras up to 0.9%. These low values are comparable to what is found in other mollusc species, and in general are well within what is regarded as intra-specific genetic distance in this gene (*e.g.*, Meyer and Paulay 2006). COI sequences from two specimens of *F. halanychi* from Iceland have been submitted to GenBank under accession numbers HG975084 and HG975085.

Discussion

A number of additional species have been hypothesized to have distributions that include the investigated area (Salvini-Plawen 1975), but have so far not been registered from Icelandic waters. This is the case in *Chaetoderma productum* Wirén, 1892 and *Ch. intermedium* Knipowitsch, 1896. While these species have not been registered from Icelandic waters, they have known distributions both east and west of Iceland, however mainly at more northern latitudes (Salvini-Plawen 1975), and it is likely that these species are in fact restricted to a more northern, Arctic distribution. The same applies to *Chaetoderma simplex* Salvini-Plawen, 1971, *Falcidens ingolfiense* Salvini-Plawen, 1971, and *Falcidens profundus* Salvini-Plawen, 1971, which have been sampled only from the type localities west of Greenland (Salvini-Plawen 1975).

The records from the samples from the IceAGE survey increase the number of known species of Caudofoveata in Icelandic waters to nine. It is expected that the number of registered species from this material will increase as the remaining material from the 2011 IceAGE cruise is sorted and investigated. Both the material sampled during the BIOICE project and the presently available material from IceAGE also contains species from the families Chaetodermatidae and Limifossoridae that remain undescribed. Material from this, and subsequent cruises will provide material for species description and further investigations to give a more comprehensive picture of the occurrence and distribution of species of Caudofoveata around Iceland.

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