

ASSESSMENT OF DIVERSITY AND DISTRIBUTION OF BENTHIC COMMUNITIES IN HOPAVÅGEN BAY, SLETVIK AREA (NORWAY)

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Abstract. The study presents the results of macrovisual characterisation of diversity and distributional pattern of benthic assemblages of fauna and flora, influenced by the hydrodynamic and geomorphological conditions in the Hopavågen Bay. The surveys were carried out by underwater *visual census* in May 2012 and August 2013, as part of the eco-hydraulic work package (PISCES) of the HYDRALAB IV project. It studied the interactions of vegetation with hydrodynamics, focusing on the ability of physical models of plants to mimic real vegetation, in order to enhance the production of more realistic surrogates. In average, 30 species of macroinvertebrates and 15 species of macrophytes have been identified. The seasonal distribution of biotic components is also presented..

Key words: Norway Sea, landlocked bay, biodiversity, benthos, underwater visual census, seasonal distribution

1. INTRODUCTION

The Hopavågen is a landlocked bay, in Agdenes, Sør-Trøndelag, Norway, characterised by a steep, rough relief, surrounded by mountains with erosion marks left by the last glaciation. It is a quite shallow basin, with a maximum depth in the central area of 31 m (Bates, Whitehead, 2001), partially isolated from the Norway Sea, with which it communicates only through a narrow channel (Straumen) (6m wide, in the narrowest place, at low tide, *personal obsv.*) (Fig. 1).

The freshwater runoff from the areas surrounding Hopavågen originates in a few small streams; thus, the volume of the freshwater is insignificant when compared to the daily inflow of seawater through Straumen (Marion, 1996). The communication with the open sea leads to an important influence of the tidal regime on the basin, an exchangeable water mass of 14% per day being estimated (Fig. 2). The tidal elevation varies from 0.3 m, during neap and up to 1 m during spring tides (Paul, 2014), while the salinity in

the inlet, depending on the thermal and tidal conditions, is close to the values found in the fjord (31 ± 4 ppm) (Paul *et al.*, 2014).

Earlier evidences on the hydrographical and biological conditions within the Straumen brought up the studies of Balchen (1971, 1979), Marion (1996). Lately, numerous publications have dealt with the hydrodynamic measurements and experimental works in relation with biotic environment (*e.g.*, Harder *et al.*, 2006; Paul, 2014; Paul *et al.*, 2014). The influence of nutrients on biota in Hopavågen area were reported in experimental studies by Kraufvelin *et al.* (2002). However, very few recent studies on the biodiversity of the Bay are available (*e.g.*, Alvsvag, 2017). The inlet presents a high diversity in terms of macrozoobenthos assemblages and phytocoenosis. *Laminaria hyperborea* forms an extensive canopy in high velocity stream of the channel as well as several remarkable abundant engineering macroinvertebrates communities of *Metridium dianthus*, *Strongylocentrotus*, *Cucumaria*, and *Ophiocomina*.

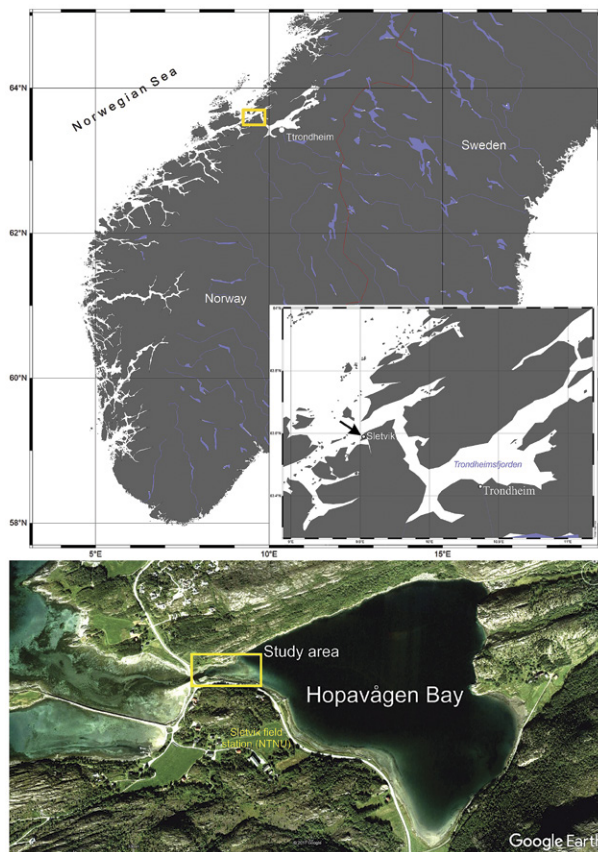


Fig. 1. Hopavågen Bay – general view and Straumen study area (source: GoogleEarth; OceanDataView).

2. MATERIAL AND METHODS

In May - June 2012 and August 2013, diving observations on the distribution, abundance, and diversity of benthic macrofauna and dominant macrophytes in the Sletvik area were carried out (Fig. 3). The photos were taken during the surveys performed along transects across the channel. For that purpose, a digital housed photo camera Canon *PowerShot SX10 IS*-10 Mpx was used. The depth in the inlet was measured with an echosound DEPTHMATE SM-5 of 400 KHz frequency.

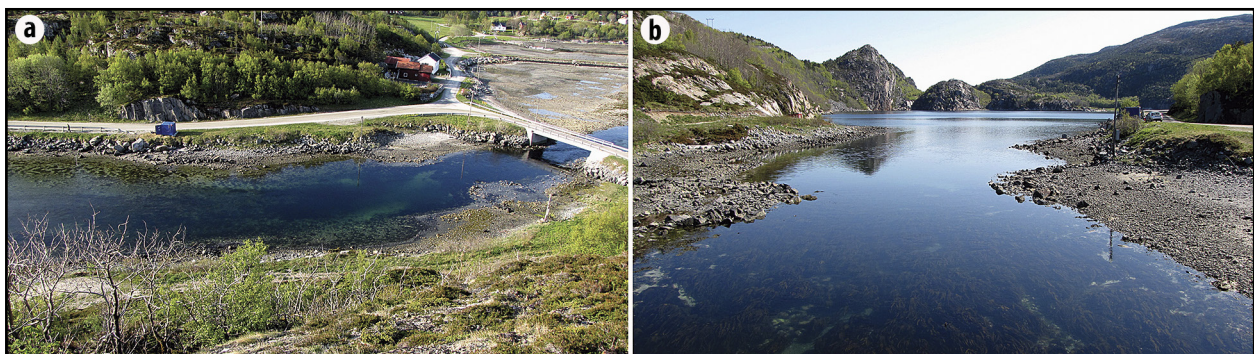


Fig. 2. Overview of the study area. **a** – photo taken from the right bank of the channel from about 20 m height; **b** – the communication channel between Bay and Norway Sea (image taken from the bridge) (Photo: A. Teacă).

The mineralogical composition of sediments was analysed according to the methods described in Parfenoff *et al.* (1970) and Mange and Maurer (1992). A Mastersizer 2000E was used for sediment grain size analysis. The sediments were classified according to the Udden-Wentworth scale and the Sheppard ternary diagram.

All species nomenclatures' have been checked according to WoRMS database (WoRMS Editorial Board, 2017).

3. RESULTS AND DISCUSSIONS

3.1. GEOMORPHOLOGY AND HYDROLOGY

The channel (from bridge to the inner part) is 170 m long, ranging between ~ 6 m (under the bridge) and 30 m width in the central part. The sediments consist of glacial origin deposits of gravels, pebbles, sand and a very low silty fraction (under 1%). The shell debris of *Littorina*, *Buccinum*, *Modiolus*, *Chlamys*, *Ensis*, *Arctica*, *Dosinia*, and cardiids, tubes of polychaetes (*Spirobranchus*), echinoderms tests, red calcareous algae *Corallina* and *Lithothamnion* contribute with about 35 – 60% to the composition of sediments (Fig. 4). At high tide, the fraction of biogenic sediments inside the inlet is periodically replenished from the shallow outside part.

The petrographic and mineralogical composition of sediments is dominated in proportion of 40-65 % by fragments of metamorphic rocks (gneiss, amphibolite, micaceous schists) and minerals (quartz, orthosis, feldspar, magnetite, ilmenite, mica, biotite, garnet, epidote, amphiboles). The quartz of various types dominated the mineral fraction.

In May 2012, a maximum current velocity of 0.4 m s^{-1} during flood tides and 0.15 m s^{-1} during ebb tides were recorded. The flow velocity can reaches up to 6 m s^{-1} in the mouth of the inlet as the slope becomes steeper (Paul *et al.*, 2014). The slope of the left bank increases slowly within about 30 m length up to the middle of the channel, where a maximum depth of 1.3 m is reached. Hence, a greater amount of sediments is accumulated on this side. In turn, the steeper slope of the rocky right bank is permanently eroded by strong currents that carry the sediments away. Upstream the mouth of the inlet, on the right bank, as well as closer to the bridge, but

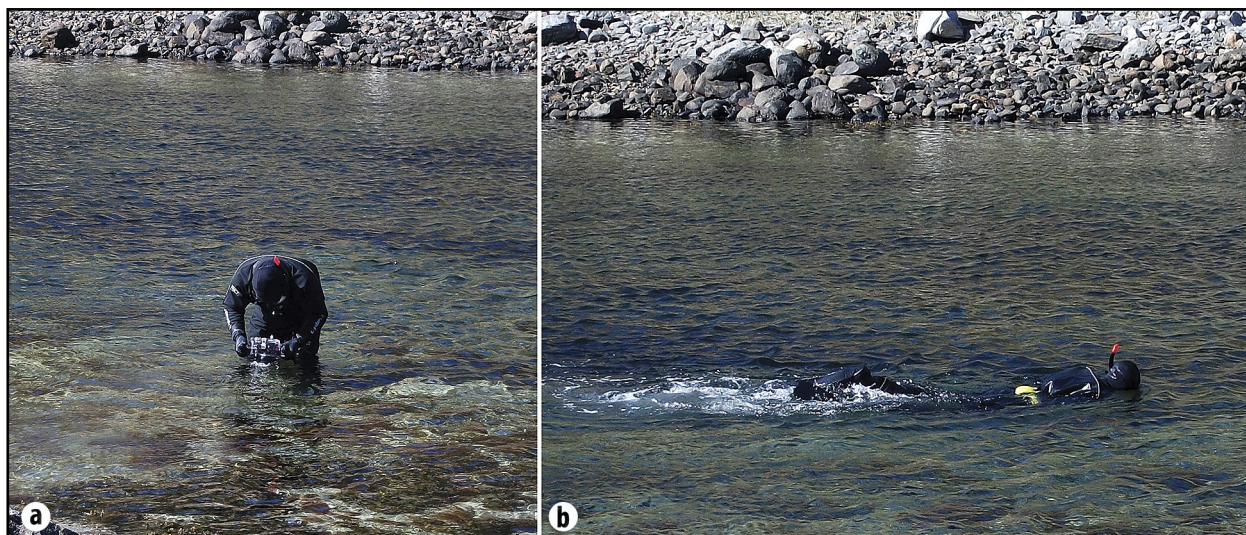


Fig. 3. a – Taking photos of fauna and algal vegetation; b – underwater *visual census* transects (Photo: C. Ungureanu).

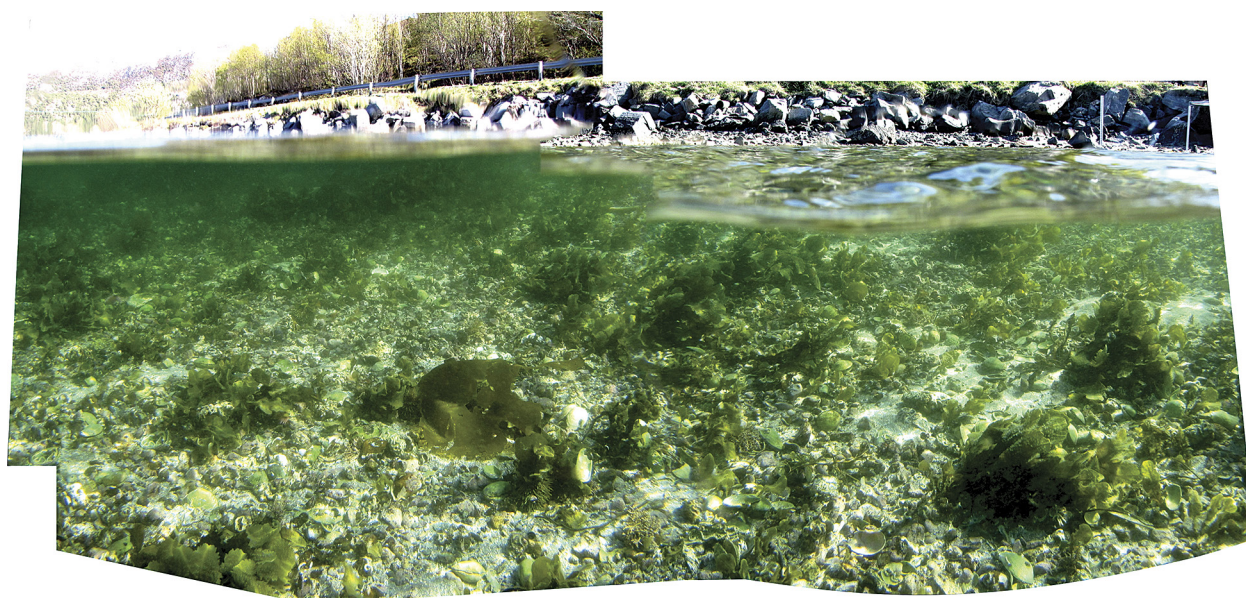


Fig. 4. Left bank seabed (panoramic image) (Photo: A. Teacă).

deeper, the eddy currents created two holes of 4 m and 3 m depth, respectively. The sedimentary processes in the holes differ significantly. Hence, in the absence of the bottom currents, the deeper hole accumulates sediments, and opposite, the shallower one is eroded as result of strong tidal bottom currents, which sweep the sediments away.

3.2. BIODIVERSITY

Macrozoobenthos

During the investigations performed in May 2011 and August 2013, 47 taxa (macroinvertebrates, vertebrates and macrophytes) (Table 1) were found. However, the small species difficult to identify were not considered within this study.

The associations of organisms observed were dominated by few large size species, accounting for more than 50% frequency: *Metridium dianthus*, *Littorina littorea*, *Buccinum undatum*, *Modiolus modiolus*, *Pagurus bernhardus*, *Carcinus maenas*, *Asterias rubens*, *Ophiopholis aculeata*, *Ophiocomina nigra*, *Strongylocentrous droebachiensis* and *Cucumaria frondosa* (Fig. 5).

M. dianthus covers about 80% of the inlet, thriving on its right bank as well as in the middle part of it, under the influence of strong currents. The species was never found in similar high number in slow or absence of currents. We therefore presume that the food supply limiting and depletion of oxygen induced by water stratification during summertime (*Metridium* is an oxyphilic species) could be the reason for this. In some sectors, *M. dianthus* forms compact fields, excluding

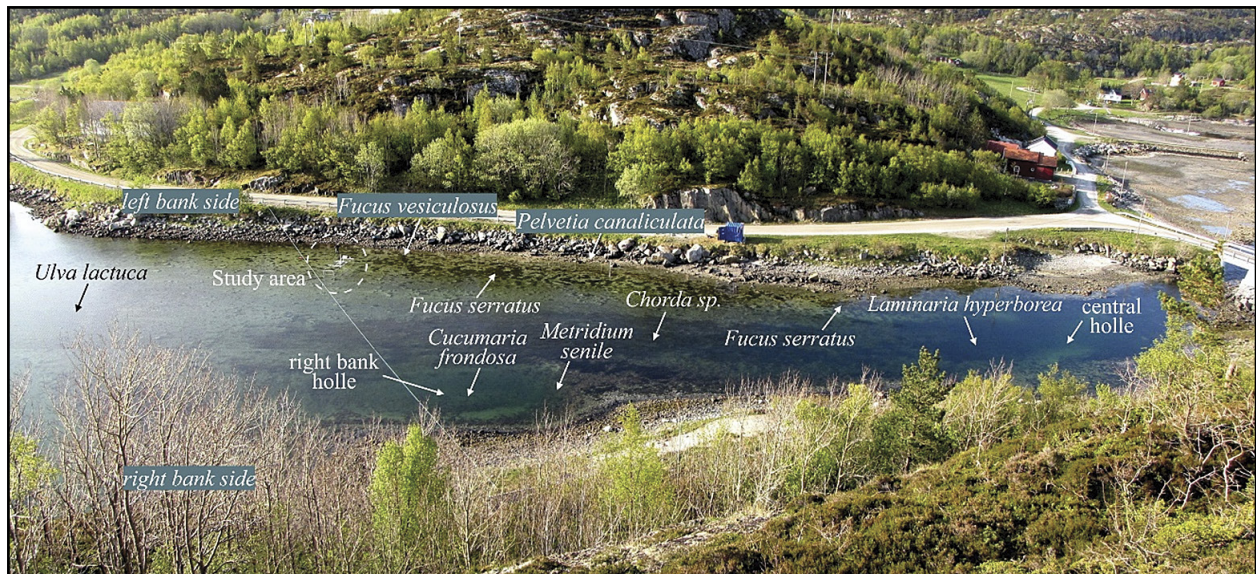


Fig. 5. The topography of the channel and distribution of phytocoenosis and of major engineering benthic species within (Photo: A. Teacă).

any potential competitive species from nearby (Fig. 6 A, B). As suspension feeder, *Metridium* controls the meroplankton populations (Nelson and Craig, 2011). Even in the case that larvae succeed to settle on the substratum, *Metridium* effectively suppresses their development by gliding over and suffocating them. Under *Metridium* foot, the oxygen drastically decreases, while the pH becomes lower than 4.45 (Woolmington and Davenport, 1983).

The mollusc *Littorina littorea* is abundant on the rocks of the shallow supralittoral and intertidal area down to 0.5 m depth, but lacks in the sublittoral. The periwinkles forage predominantly on the rock surface and amongst the understory of ephemeral algae or even prey on small invertebrates and barnacle larvae. Watson and Norton, (1985) and Imrie et al, 1990 showed that *L. littorea* can be highly selective, a preference for the green (*Ulva lactuca*, *Enteromorpha*) and red algae (e.g., *Porphyra umbilicalis*) being documented. The mollusc is, in turn, preyed by birds or other invertebrates.

As going deeper, the periwinkle is replaced by the whelk *Buccinum*, which inhabits the sublittoral sedimentary substratum, occasionally reaching in the midlittoral upper zone (Fig. 6 G). Usually, it avoids the salinity variations from the intertidal area. It feeds upon small molluscs (bivalves), other predators' scraps, and as some studies suggested, the whelk is even a carrion feeder (Himmelman and Hamel, 1993). It searches actively for food in long distances unlike *Littorina*, which crawls just around the rock it grazes on in the daytime.

After gastropods death, their shells are used for sheltering by other species such as the hermit crabs that can be found within the shells of whelk as adults and within those of *L. littorea*, as young (Fig. 6 H).

The coarse sediments are mostly occupied by the bivalves, such as *Modiolus modiolus* (Fig. 7 A), unevenly distributed clumps of two-three individuals being often spotted in

the macrophytes' meadows. Attached to their shells a rich epibenthic fauna of algae and tube dwelling polychaets was noted. Less numerous were, in general, the endopsamic species *Ensis* or *Mya* and, among the epibenthic ones, *Chlamys* (Fig. 7 B, C, D).

Along with the molluscs, the calcareous tube-dwelling polychaetes (*Spirobranchus*) within the inlet contribute primarily to the genesis of biogenic sediments and secondary, at creating habitat niches used by cryptic invertebrate species or algae, as shelter or support (Fig. 6 F). *Arenicola marina*, abundant within the muddy sediments outside the channel, plays also a significant role in modelling the sediments' aspect. The physiological activities of the lugworm such as nutrition, producing of faecal casts and mechanical reworking of sediments by burying into "U" galleries (Fig. 6 E) yield an intense bioturbation effect on sediments that results in increased oxygen penetration and transport of chemical gradients (Rasmussen et al, 1998).

Active omnivorous and vagile species *Pagurus bernhardus* and *Carcinus maenas* were the most common decapods noted in the area (Fig. 7 E, F). The pagurids inhabit mostly the sedimentary left side of the channel, while the crabs occupy large areas, patched in small groups, wandering off all over the place, in search of food. Occasionally, the less motile anemur *Galathea squamifera* and the crab *Hyas* sp. were spotted, the latter one in the deep part of the channel, perfectly disguised in algal or hydroid epibiosis (Fig. 7 G, H).

The echinoderms were very abundant in the inlet, especially some gregarious species of ophiuroids and sea cucumbers. *Marthasterias glacialis* and *Asterias rubens* from Asterozoa, *Ophiopholis aculeata* and *Ophiocomina nigra* from Ophiurozoa, *Strongylocentrotus droebachiensis* and *Echinus esculentus* from Echinozoa and *Cucumaria frondosa* from Holothurozoa were the most common species iden-

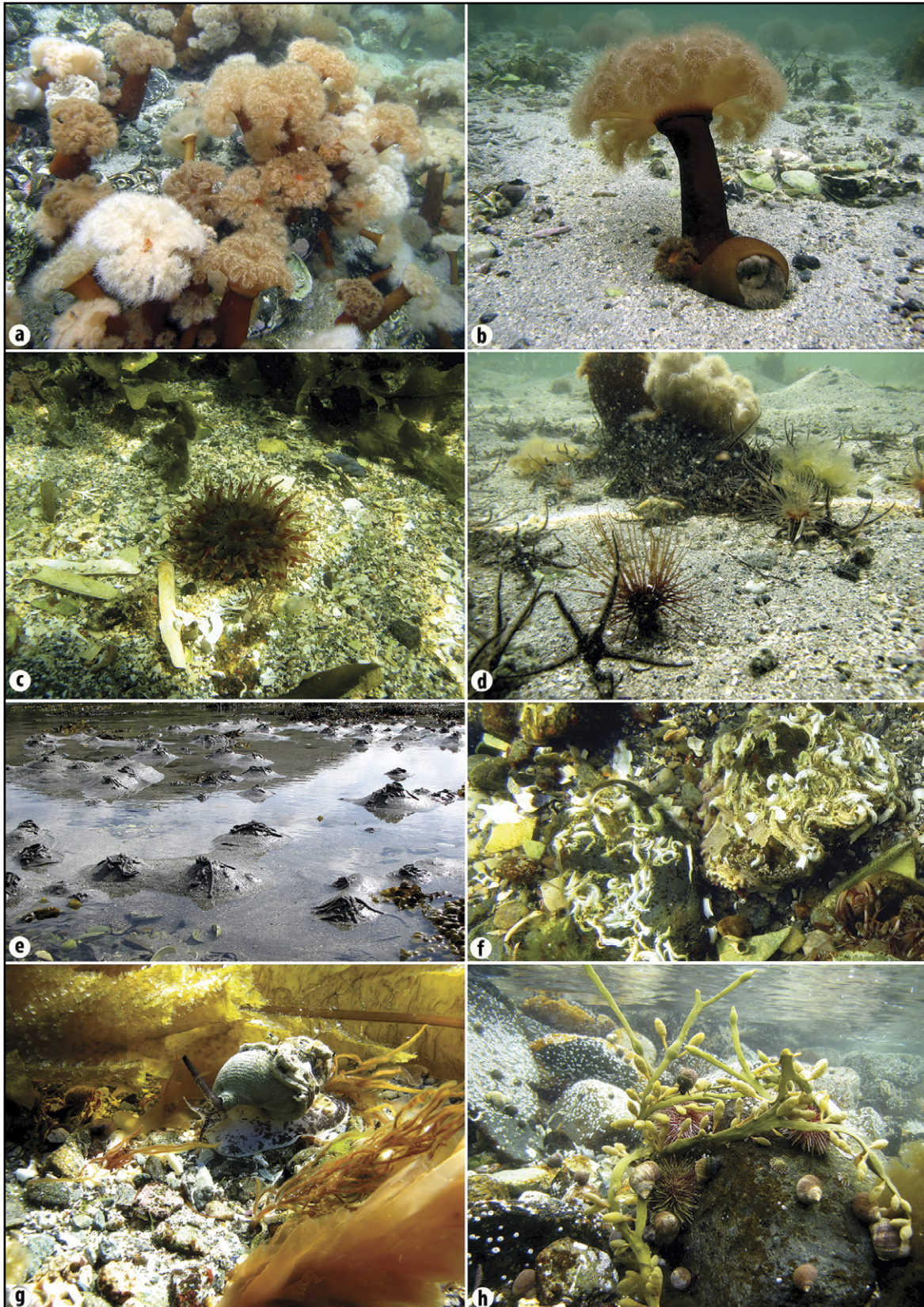


Fig. 6. **a** – *Metridium dianthus* population on the right bank of the channel (inside the right bank hole); **b** – a solitary individual of *Metridium*; **c** – Sea anemone; **d** – *Cerianthus lloydii* found in the deeper inner part of the inlet; **e** – *Arenicola marina* sporadically present within the channel but widely distributed outside it; **f** – Calcareous tubes of *Spirobranchus triqueter* – biogenic source of sediments; **g** – *Buccinum undatum*; **h** – *Littorina littorea*, from shallow waters, grazing bacterial/algal film on rocks and brown alga *Ascophyllum nodosum* (Photo: A. Teacă).

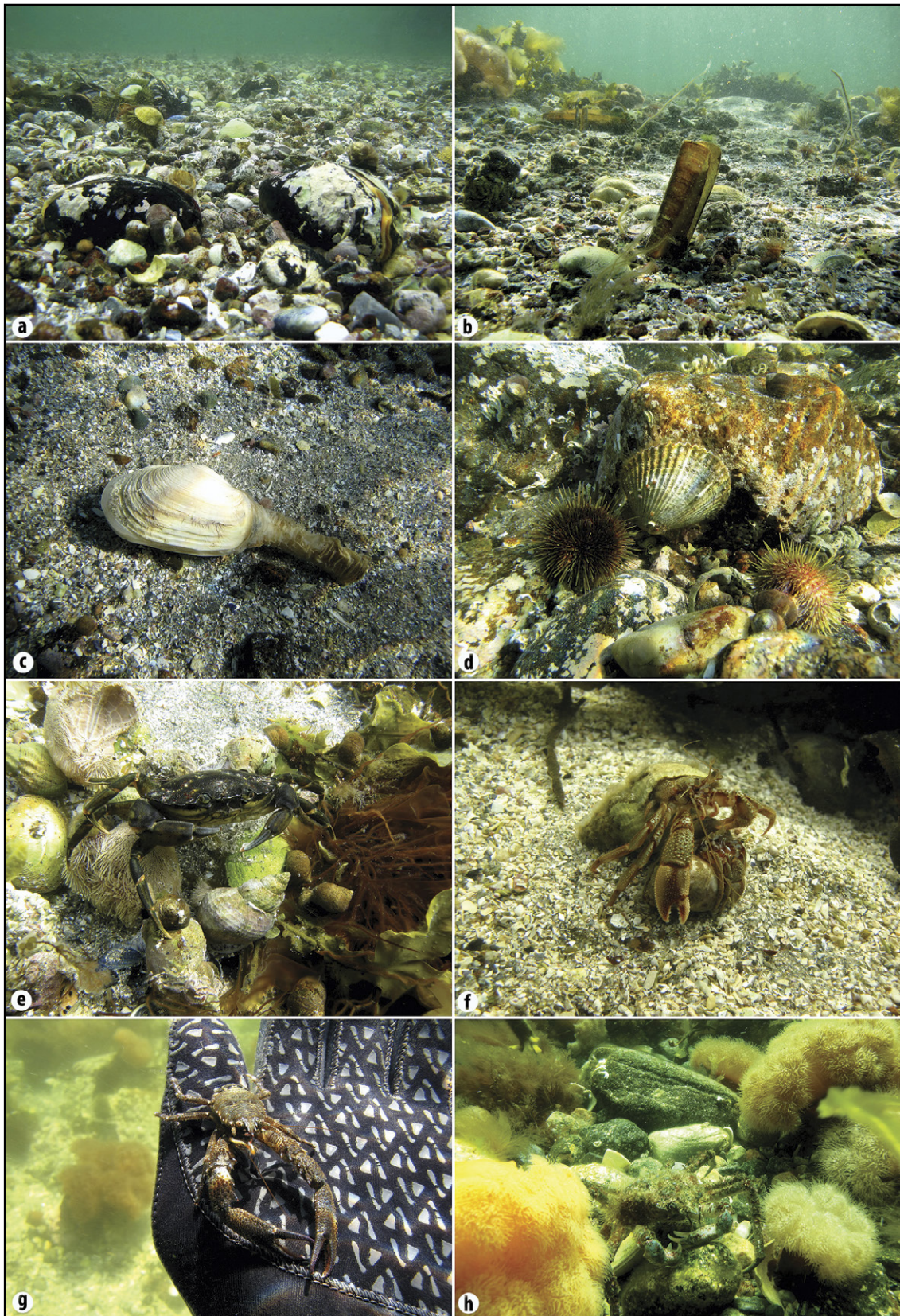


Fig. 7. a – *Modiolus modiolus* clumps; b – Endopsamic bivalves *Ensis* sp. and c – *Mya truncata*; d – *Chlamys varia*; e – Decapods *Carcinus maenas* and f – *Pagurus bernhardus*; g – Cryptic decapods *Galathea squamifera* and h – *Hyas* sp. (Photo: A. Teacă).

tified (Fig. 8). Having few natural enemies (e.g. birds), their proliferation may affect the ecosystem functionality and structure. Most obvious is the grazing effect of *Strongylocentrotus* on the macrophytes within the fjord. *Laminaria*, especially, was severely damaged in some years. The big size (10 – 12 cm) sea star *Asterias rubens* lives on both sides of the channel in low abundances (in groups of 2 – 3 individuals), while the juvenile stages rather prefer the meadows of macrophytes from the left bank (Fig. 8 A). Solitary individuals of *Marthasterias* were noticed only in the deep part of the channel (Fig. 8 B). The cryptic behaviour ophiuroids are usually found under rocks or algae holdfasts in shallow exposed areas. *Ophiocomina* gathers in spectacular assemblages of hundreds of individuals on sedimentary substratum in the deep inner part of the Bay (Fig. 8 C). Its population occupies an area of up to 40 – 60 m², at 3 – 6 m depth. *Ophiopholis* is also frequent in shallow waters, though it does not attain important densities (Fig. 8 D).

The sea urchin *Strongylocentrotus droebachiensis* is the second dominant species as regards the biomass, after *Metridium* (Fig. 8 F). It is a voracious predator, eating small invertebrates (polychaetes, crustaceans, molluscs) and macrophytes (especially, *Laminaria*). The active “grazing” hinders epibiosis development on hard substratum by limiting red encrusting algae, *Balanus*, and *Spirobranchus* growth. The species forms cohorts of 15 – 20 individuals (sometimes, of 40 – 50 ind/m²) in the algae thickets (*Laminaria digitata*, *L. hyperborea*, *Fucus serratus*, *F. vesiculosus*), that can be suppressed by the urchins. *Echinus esculentus* was sporadically met in small populations (Fig. 8 G). Sea urchins exoskeleton contributes to sediment genesis. *Cucumaria frondosa* is a suspension feeder species, which prefers the right bank area, where strong currents prevail (Fig. 8 E). It forms compact agglomerations (tens of individuals) in the deep zone in association with *Metridium*.

Macrophytes

Distinct distribution of the main algal coenoses made possible their easy observation by *visual census*. Six major phytocoenoses were identified within the channel, regardless of accessory species (some red and brown filamentous algae), which do not form distinct belts or associations (Fig. 5 and 9). Fifteen dominant macrophytes species were identified, in majority brown algae (10 species) (Table 1).

Pelvetia canaliculata coenosis forms the first algal belt situated just above the upper limit of the tide level, scattered on the sheltered rocks along the entire length of the left bank of the channel (Fig. 10 A). It represents an ecotone zone for many species able to support the emersion (e.g. *Littorina*, crabs).

Fucus vesiculosus coenosis forms the second belt situated in the intertidal zone (eulittoral or midlittoral) (Fig. 10 B). It looks like a 1 – 1.5 m wide discontinuous band on the left side of the sheltered area of the inlet. The slope of the bank prevents its complete exposure at low tide. Near the bridge, the belt continuity ceases because of very strong currents.

Outside the channel, the coenosis, which reaches 3.5 m in width, suffers from periodic emersion. Solitary meadows of *F. vesiculosus* could also be found in the coenosis dominated by *Fucus serratus*.

Fucus serratus coenosis forms a distinct belt of 6 – 7 m width with densities of up to 4 – 6 indv/m² in sublittoral zone, mostly spread on the left side bank within sheltered or semiexposed zones (at 60 – 70 cm depth, at low tide). It is the third species as importance and abundance in the channel (Fig. 10 C). As going deeper, its distribution becomes scattered and the height of thalli decreases. Often, *Alaria esculenta*, *Laminaria digitata* and *Colpomenia peregrina* are found in association. It shelters many vagile organisms, encrusting and colonial species (hydroids, bryozoans).

The central part of the channel is occupied by *Chorda* coenosis (Fig. 10 D). It is the second species in abundance in the central part of the inlet strongly affected by the currents. *Metridium* also forms compact populations in between algal thalli.

Laminaria hyperborea forms the largest compact coenosis situated in the most exposed area near and under the bridge, occupying, in fact, the entire channel from the bridge to the *Chorda*'s coenosis (Fig. 10 E, F). The species of about 3 m height is attached to the substrate through a strong holdfast that continues with a long, rigid stipe that regularly remains exposed at low tide. The lamina is flat and has a length of 1.5 – 2 m. Epiphytic algae (e.g., *Delesseria sanguinea*) cover the harsh basal part of the stipe. Many benthic invertebrates (e.g., nemerteans, polychaetes, crabs, and ophiuroids) lay under *Laminaria*'s holdfast.

Laminaria digitata does not form a distinct coenosis, the species being mostly associated with *Fucus serratus* (Fig. 10 G). It has a reduced abundance within the study area.

Ulva lactuca is the only green algae largely spread within the inner shallow part of the channel (0.5 m depth) on the mixed coarse and shelly sediments (Fig. 10 H). It lives in association with specimens of red filamentous algae, which are considered of minor importance after their proportion within the coenosis.

Articulate calcareous and encrusting algae play an important role in sediments' genesis within the channel. Two red algae species, *Corallina officinalis* and *Lithothamnion* sp., were identified (Fig. 11 A, B). *C. officinalis* has relatively low abundances within the channel than outside it (towards the sea), where the calcareous remains form a thick bed. *Lithothamnion*, on the other hand, covers the hard substratum of the entire area of the inlet. Since it is not sensitive to tidal currents, it occupies any rocky substrate, free of algae or *Metridium*.

The green algae *Codium* and the brown algae *Halidrys* and *Ascophyllum* are rarely found within the channel (Fig. 11 C, D). *Codium* was observed in the sector exposed to the tid-

Table 1. Taxonomic list of fauna and algal vegetation identified and their ecological traits

No. crt.	Phylum	Taxa	Ecological traits				
			Feeding type	Tolerance to emerssion	Tolerance to hydrodynamism	Biotope/ Benthic zone	Sediments genesis
1	Cnidaria	<i>Metridium dianthus</i> (Ellis, 1768)	S	n	t	hard/sublitt.	
2	Cnidaria	Anemone indet 1	S	n	n	hard/sublitt.	
3	Cnidaria	Anemone indet 2	S	n	n	hard/sublitt.	
4	Cnidaria	<i>Cerianthus lloydii</i> Gosse, 1859	S	n	n	sed./sublitt.	
5	Nemertea	<i>Lineus longissimus</i> (Gunnerus, 1770)	P	n	n	mix/sublit.	
6	Annelida	<i>Arenicola marina</i> (Linnaeus, 1758)	D	t	n	sed./intertid.	
7	Annelida	<i>Spirobranchus triqueter</i> (Linnaeus, 1758)	S,F	n	t	hard/sublitt.	+
8	Mollusca	<i>Leptochiton</i> sp.	G	m	t	hard/sublitt.	
9	Mollusca	<i>Littorina littorea</i> (Linnaeus, 1758)	O	t	m	mix/intertid.	+
10	Mollusca	<i>Buccinum undatum</i> Linnaeus, 1758	P	n	n	mix/sublit.	+
11	Mollusca	<i>Doris pseudoargus</i> Rapp, 1827	P	n	n	hard/sublitt.	
12	Mollusca	<i>Chlamys varia</i> (Linnaeus, 1758)	F	n	m	hard/sublitt.	+
13	Mollusca	<i>Modiolus modiolus</i> (Linnaeus, 1758)	F	n	m	hard/sublitt.	+
14	Mollusca	<i>Mya truncata</i> Linnaeus, 1758	F	n	n	sed./sublitt.	+
15	Mollusca	<i>Ensis</i> sp.	F	n	n	sed./sublitt.	+
16	Bryozoa	Bryozoa spp.	S	n	t	hard/sublitt.	
17	Arthropoda	<i>Balanus balanus</i> (Linnaeus, 1758)	S	t	t	hard/intertid.-sublitt.	
18	Arthropoda	<i>Pagurus bernhardus</i> (Linnaeus, 1758)	O	t	n	mix/intertid.-sublitt.	+
19	Arthropoda	<i>Galathea squamifera</i> Leach, 1814	O	n	n	hard/sublitt.	+
20	Arthropoda	<i>Hyas</i> sp.	O	n	n	mix/sublitt.	+
21	Arthropoda	<i>Carcinus maenas</i> (Linnaeus, 1758)	O	t	m	mix/intertid.-sublitt.	+
22	Arthropoda	<i>Cancer pagurus</i> Linnaeus, 1758	O	m	t	mix/intertid.-sublitt.	+
23	Echinodermata	<i>Marthasterias glacialis</i> (Linnaeus, 1758)	P	n	n	mix/sublitt.	+
24	Echinodermata	<i>Asterias rubens</i> Linnaeus, 1758	P	n	m	mix/sublitt.	+
25	Echinodermata	<i>Ophiopholis aculeata</i> (Linnaeus, 1767)	F,D,O	n	n	mix/sublitt.	+
26	Echinodermata	<i>Ophiocomina nigra</i> (Abildgaard in O.F. Müller, 1789)	F,D,O	n	n	mix/sublitt.	+
27	Echinodermata	<i>Strongylocentrotus droebachiensis</i> (O.F. Müller, 1776)	O, G	n	m	mix/sublitt.	+
28	Echinodermata	<i>Echinus esculentus</i> Linnaeus, 1758	O, G	n	m	mix/sublit.	+
29	Echinodermata	<i>Cucumaria frondosa</i> (Gunnerus, 1767)	S	n	t	mix/sublitt.	
30	Chordata (Tunicata)	<i>Ciona intestinalis</i> (Linnaeus, 1767)	F	n	n	hard/sublitt.	

Table 1 (continued)

No. crt.	Phylum	Taxa	Ecological traits				
			Feeding type	Tolerance to emersion	Tolerance to hydrodynamism	Biotope/Benthic zone	Sediments genesis
31	Chordata (Pisces)	<i>Myoxocephalus scorpius</i> (Linnaeus, 1758)	P	n	t	hard/sublitt.	
32	Chordata (Pisces)	<i>Microstomus kitt</i> (Walbaum, 1792)	P	n	n	sed./sublitt.	

Legend
S - suspension feeders; P- predator; D – deposit feeders; F - filter feeding; O – omnivorous; G - grazers
n - nontolerant; t - tolerant; m - moderate tolerant
hard – hard substratum (rocky, hard part of the living organisms); sed. - sedimentary substrata (sand, mud); mix – mixed substrata (pebbles, gravels, sand); intertid. - intertidal zone; sublitt. - sublittoral zone

No. crt.	Class	Taxa	Ecological traits				
			Tolerance to emersion	Tolerance to hydrodynamism	Benthic zone	Phytocoenosis	Sediments genesis
1	Phaeophyceae	<i>Pelvetia canaliculata</i> (Linnaeus) Decaisne & Thuret, 1845	t	n	supralitt.	+	
2	Phaeophyceae	<i>Fucus vesiculosus</i> Linnaeus, 1753	t	n	intertid.	+	
3	Phaeophyceae	<i>Fucus serratus</i> Linnaeus, 1753	m	n	sublitt.	+	
4	Phaeophyceae	<i>Laminaria hyperborea</i> (Gunnerus) Foslie, 1884	m	t	sublitt.	+	
5	Phaeophyceae	<i>Laminaria digitata</i> (Hudson) J.V.Lamouroux, 1813	m	m	sublitt.	-	
6	Phaeophyceae	<i>Chorda</i> sp.	n	t	sublitt.	+	
7	Phaeophyceae	<i>Alaria esculenta</i> (Linnaeus) Greville, 1830	n	n	sublitt.	-	
8	Phaeophyceae	<i>Ascophyllum nodosum</i> (Linnaeus) Le Jolis, 1863	t	m	intertid.-sublitt.	+	
9	Phaeophyceae	<i>Colpomenia peregrina</i> Sauvageau, 1927	n	n	sublitt.	-	
10	Phaeophyceae	<i>Halidrys siliquosa</i> (Linnaeus) Lyngbye, 1819	n	m	sublitt.	-	
11	Ulvophyceae	<i>Ulva lactuca</i> Linnaeus, 1753	n	n	sublitt.	+	
12	Bryopsidophyceae	<i>Codium</i> sp.	n	t	sublitt.	-	
13	Florideophyceae	<i>Corallina officinalis</i> Linnaeus, 1758	n	t	sublitt.	+	+
14	Florideophyceae	<i>Lithothamnion</i> sp.	m	t	intertid.-sublitt.	-	+
15	Florideophyceae	<i>Delesseria sanguinea</i> (Hudson) J.V.Lamouroux, 1813	n	t	sublitt.	-	

Legend
n - nontolerant; t - tolerant; m - moderate tolerant
supralitt. – supralittoral zone; intertid. - intertidal zone; sublitt. - sublittoral zone

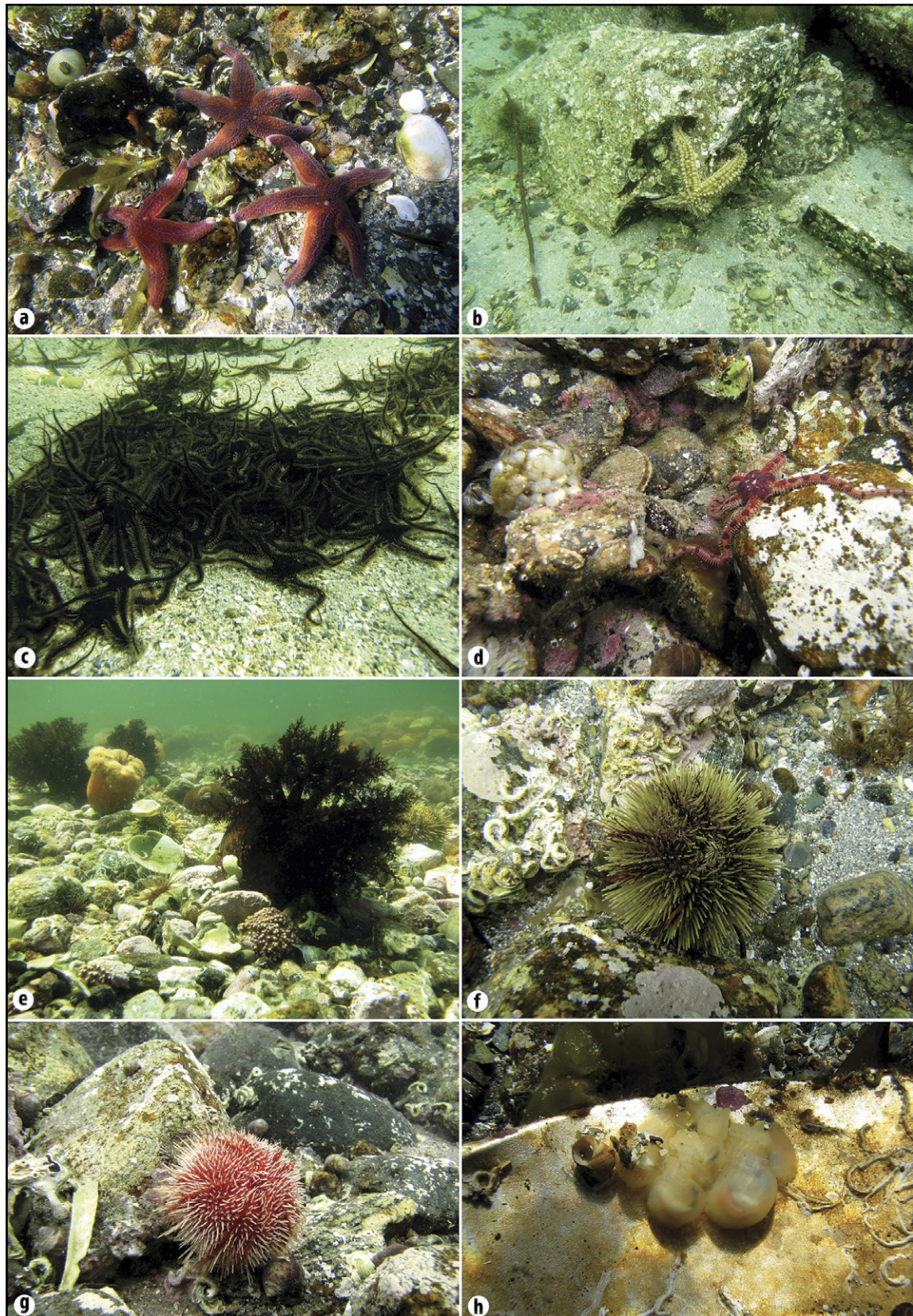


Fig. 8. The seastar **a** – *Asterias rubens* and **b** – *Marthasterias glacialis*, rarely noticed in the channel; **c** – *Ophiocomina nigra* assemblages from the inner part of the Bay; **d** – *Ophiopholis aculeata*, *Chlamys* and *Buccinum* spawn; **e** – *Cucumaria frondosa* in association with *Metridium* within the deeper parts of the right bank; The sea urchins **f** – *Strongylocentrotus droebachiensis* and **g** – *Echinus esculentus*; **h** – The tunicate *Ciona intestinalis* (Photo: A. Teacă).

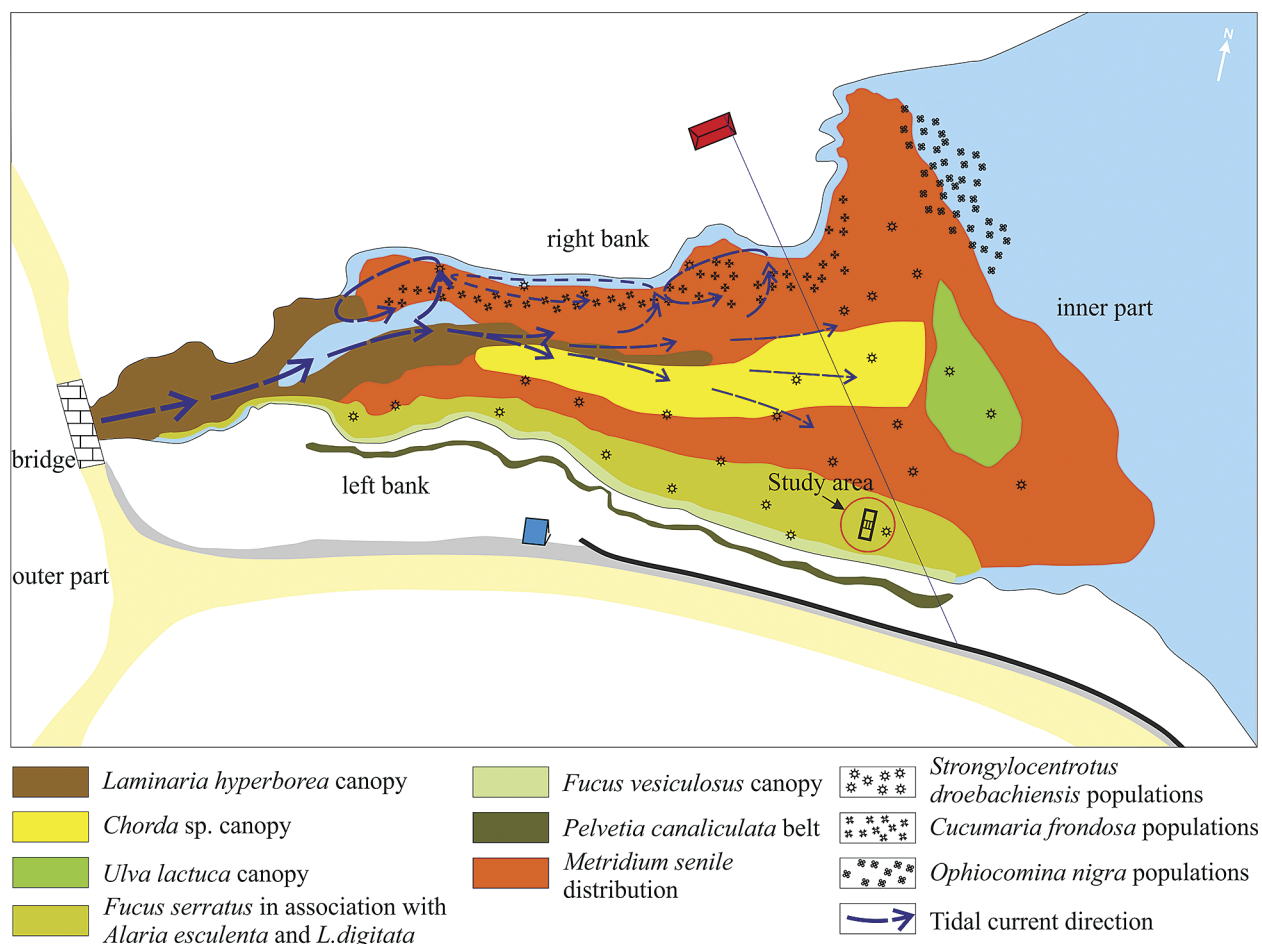


Fig. 9. Major communities of benthic invertebrates and macrophytes within the inlet (original).

al current, while *Ascophyllum* forms a distinct coenosis outside the channel, in close vicinity of *Fucus vesiculosus* belt.

The brown algae *Alaria* and *Colpomenia* within the *Fucus serratus* belt were frequently seen (Fig. 11 E, F). *Colpomenia* is an invasive species introduced in Europe at the beginning of 20th century, from Pacific. It is usually fixed on rocks and algae (*Fucus*), but sometimes can be flushed away by currents.

3.3. ECOLOGICAL SEASONAL SUCCESSION OF THE MACROBENTHIC COMMUNITIES IN 2012 AND 2013

Seasonal succession is a periodic change arising from fluctuating species interactions or recurrent events and it is not dependent on anthropogenic disturbance. In areas with important thermic variations, the underwater landscape changes seasonally. Due to the Norway current, a branch of Gulf Stream, the Norway Sea does not freeze, so the average temperature of water surface ranges between +2 and +7 °C in February, and between +8 and +12 °C, in August. That is why the benthic fauna is formed of cryophilic species, which would not tolerate long periods with high water temperatures. This is best noticed in the sheltered shallow areas, as is the case of the Hopavågen Gulf, where the increasing

temperature during the summer time affects drastically the flora and fauna from the fjord.

Comparing *in situ* observations on macrophytes and benthic fauna, in May 2012 and August 2013, in conditions of thermic regime shift from 6 - 8°C to 17 - 18°C, a very different situation was recorded. The rainy days in August caused a significant input of freshwater, which entered the Bay loaded with chemical compounds washed from the surrounding abrupt slopes covered by dense vegetation of coniferous trees and peat. The vegetal tannins and peat dissolved in water coloured it in brown and decreased its transparency for about two weeks.

Some of the macrophytic communities, such as *Chorda* from the middle of the channel, and the coceanotic species *Alaria esculenta* and *Colpomenia peregrina* dominant in spring disappeared in August, while others (*Fucus serratus* coenosis) showed distinct signs of senescence. The drastic reduction of communities of macrophytes in the middle of the channel left a bare landscape behind. However, in the deeper part, the dense meadows of *Laminaria hyperborea* and *Fucus serratus* remained intact. It is worth noting the rich bryozoan epibiosis covering in proportion of 50 % the thalli of *L. hyperborea* (Fig. 12).

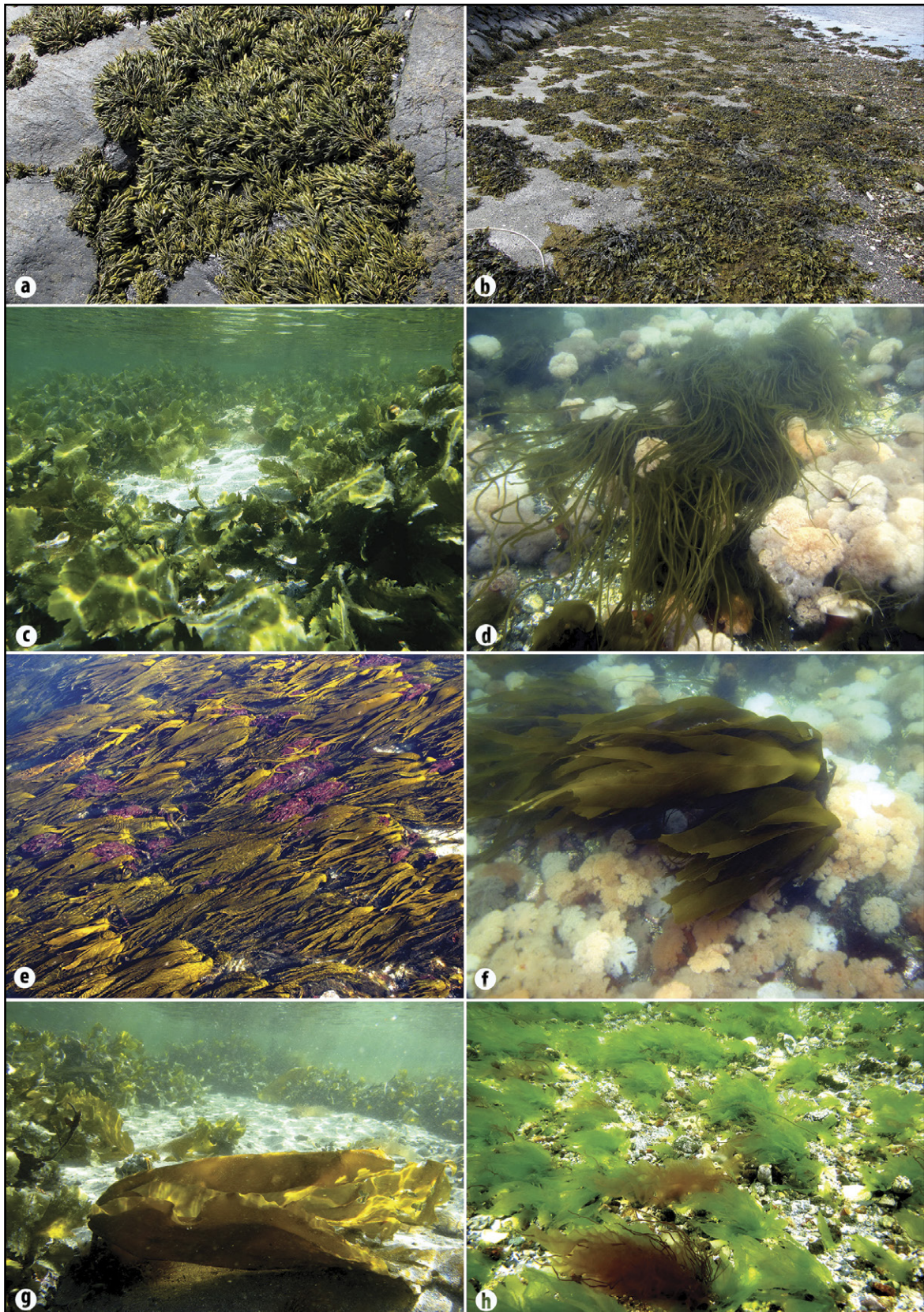


Fig. 10. **a** – *Pelvetia canaliculata* on rocky supralittoral; **b** – Intertidal belt of *Fucus vesiculosus* outside of the channel; **c** – Sublittoral belt with *Fucus serratus* within the study area; **d** – Sublittoral coenosis with *Chorda* sp. and compact population of *Metridium* in the central part of the channel; **e** – Shallow water field of *Laminaria hyperborea* epiphytized by *Delesseria sanguinea* (near bridge) and **(f)** from central part of the channel; **g** – *Laminaria digitata* from *Fucus serratus* coenosis; **h** – *Ulva lactuca* in association with filamentous red algae in shallow water.

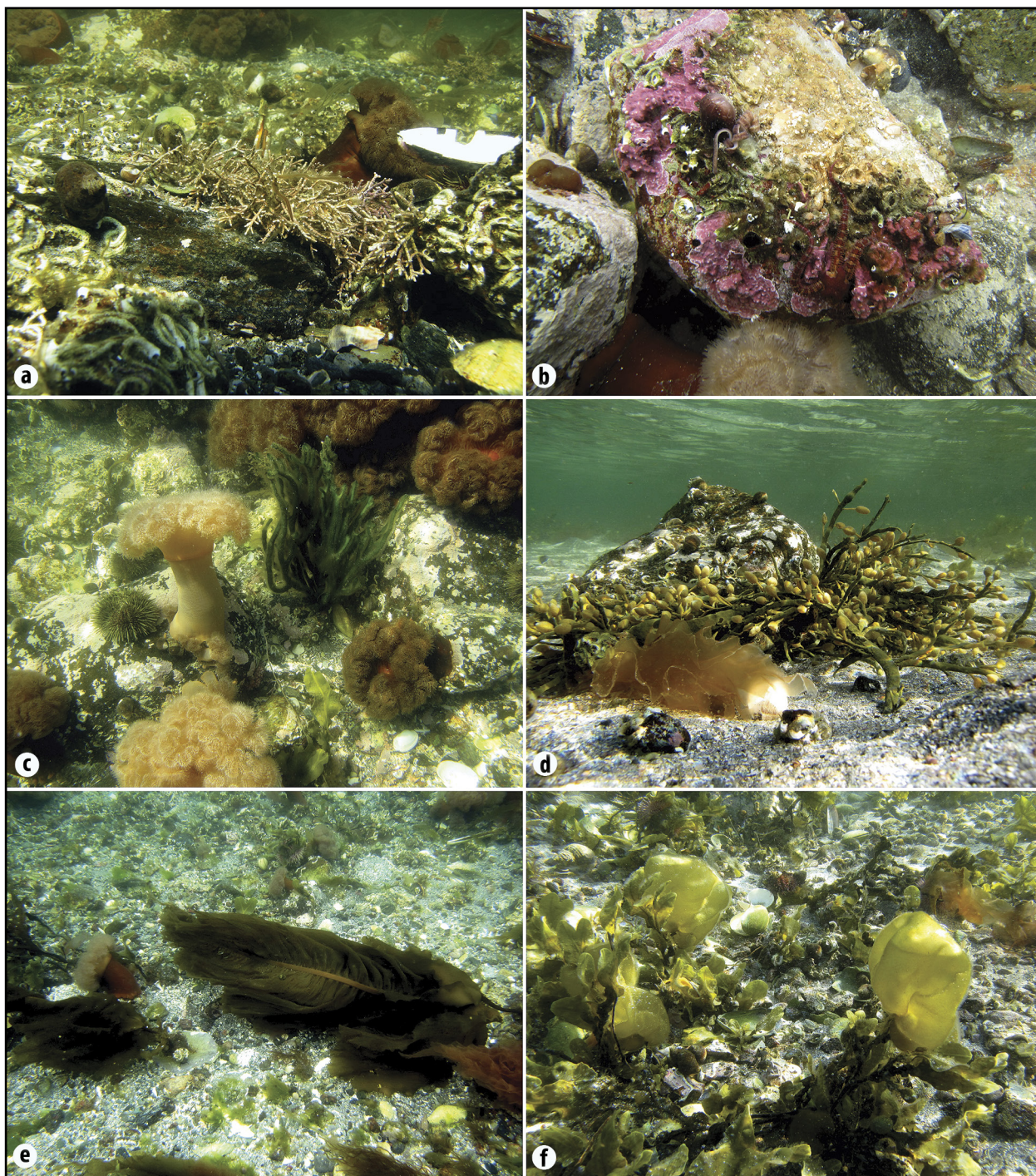


Fig. 11. Calcareous algae *Corallina officinalis* (a) and *Lithothamnion* sp. (b); *Codium* sp. observed in turbulent deep zone (c) and *Ascophyllum nodosum* (d); *Alaria esculenta* (e) and *Colpomenia peregrina* (f) associated to *Fucus serratus* coenosis (Photo: A. Teacă).

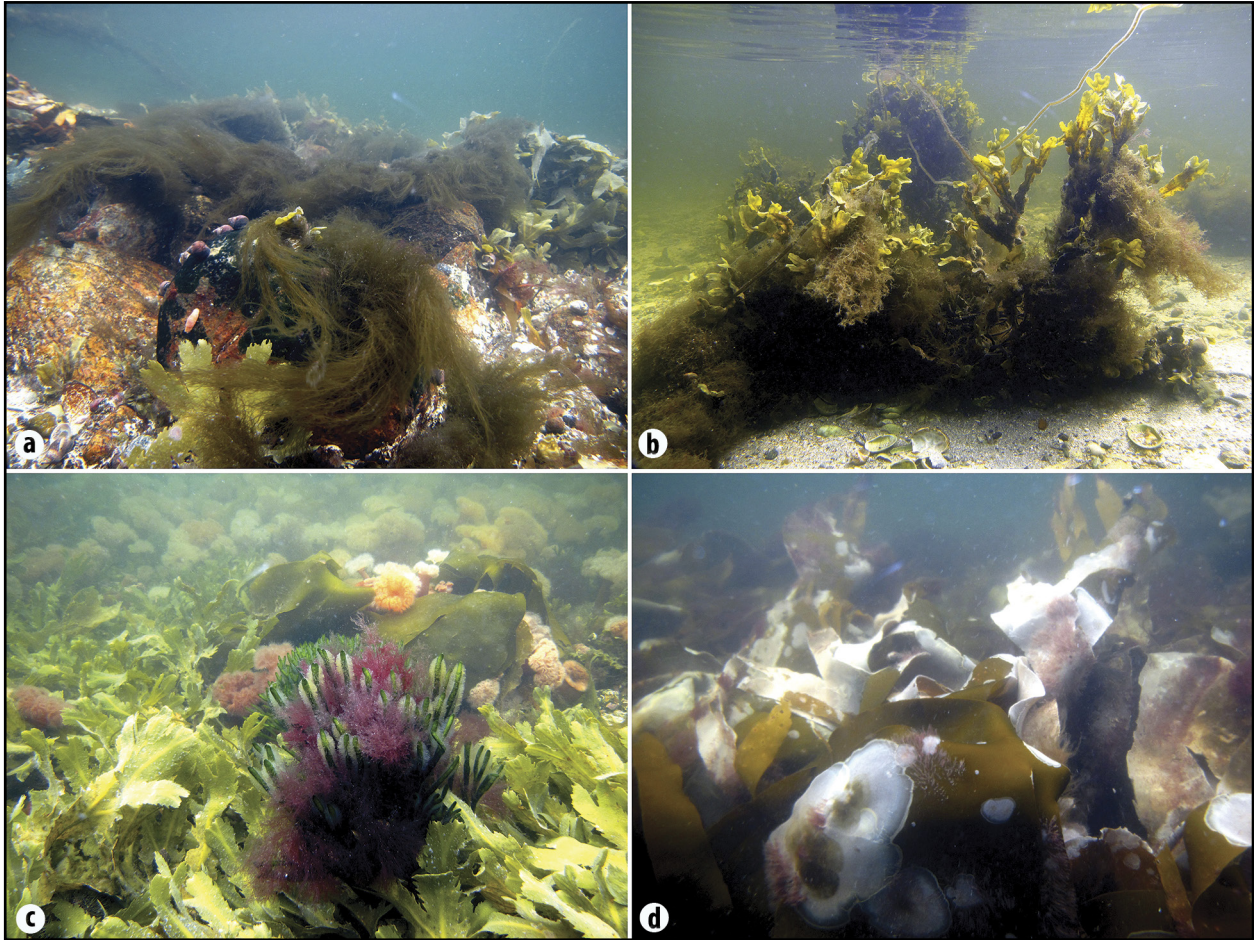


Fig. 12. The macrophytes' aspect in summer time. **a** – The central part of the inlet, in spring, populated by *Chorda* sp., invaded by brown filamentous alga; **b** – *Fucus vesiculosus* covered by annual epiphytes filamentous algae; **c** – *Codium* sp. suffocated by filamentous annual red algae; **d** – *Laminaria hyperborea* from the deep zone of the channel covered by bryozoans crusts (Photo: A. Teacă).

Nor did the macrophytes communities outside the channel show any sign of decaying. Wealthy populations of *Corallina officinalis*, encrusting calcareous algae, as well as *Fucus vesiculosus* and *L. hyperborea* covered by filamentous annual alga were still present (Fig. 13).

The reduction of *Laminaria digitata* stocks determined a considerable decreasing of abundance of phytophagous and omnivorous macrobenthic species, such as *Strongylocentrotus droebachiensis* (Fig. 13 F). The population of *Echinus esculentus* was less affected, no major changes in abundance between spring and summer being observed.

Similarly, the suspension feeders and filtering species *Metridium*, *Cucumaria* and *Ophiocomina* remained the dominant species in terms of abundance and biomass within the channel. It seems that, neither the food limitation, nor the thermal regime shift have affected them at all. The gastro-

pods *Buccinum* and *Littorina* have not suffered any visible changes either. On the contrary, the reptant decapods, especially *Carcinus maenas*, had greater stocks as compared to May. The exemplars were in majority adults of big size (8 – 9 cm carapace size). Instead, a slight reduction of abundance of sessile species, such as *Modiolus modiolus* was noticed.

The role of *Laminaria* for biodiversity, physical and chemical processes within the area was schematised in a hypothetical scenario, which took into consideration the disappearance of the algae (Fig 14). The most obvious changes occur at the level of hydrology, geomorphology, biochemical cycle of nutrients and carbon (Kelly, 2005). The biodiversity associated with the algae suffer a dramatic reduction, numerous species depending on it for food (Tait, 2010), shelter, or reproduction.

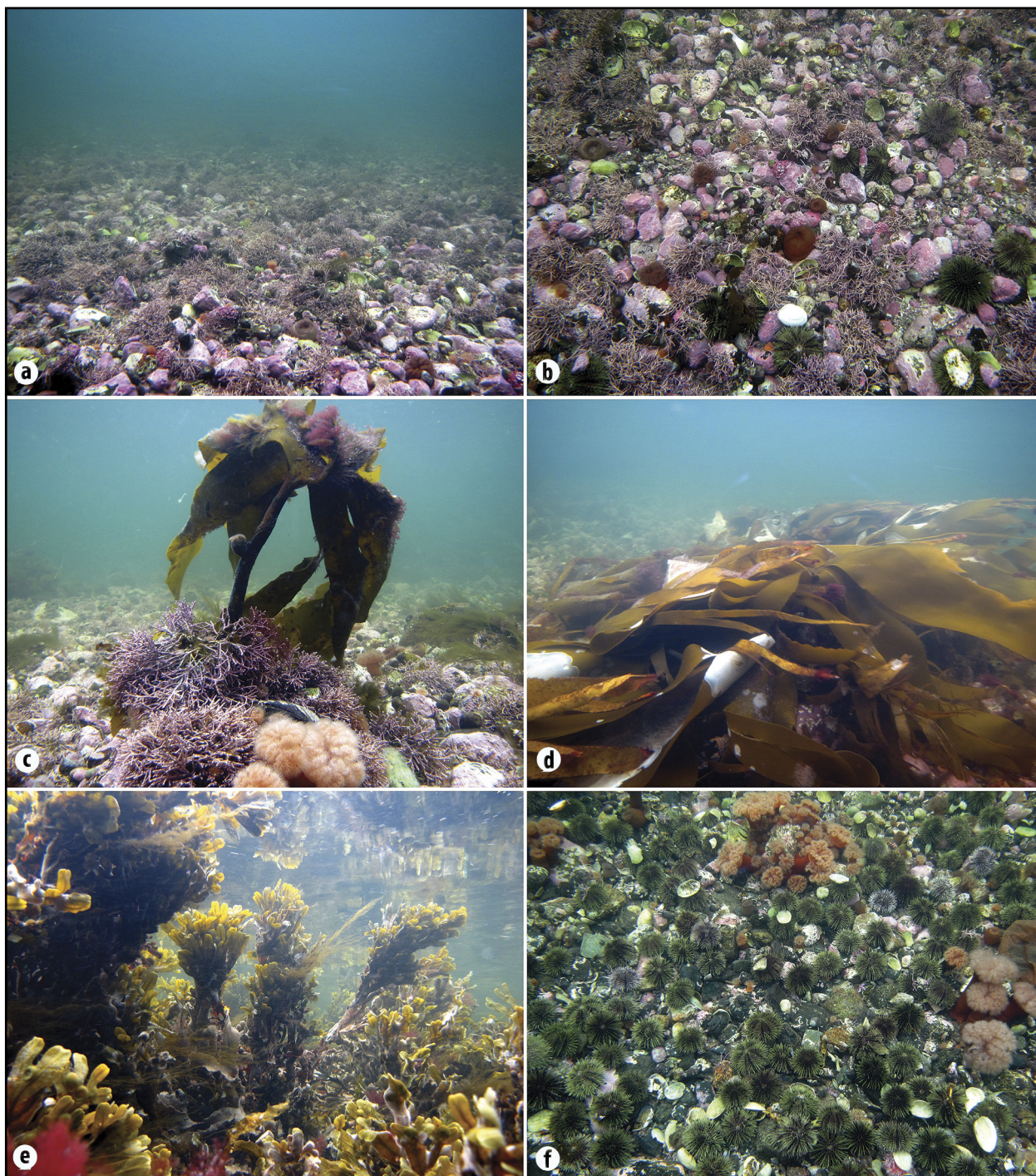


Fig. 13. The underwater landscape from the outside of the channel. **a, b** – the central area, influenced by the strong tide current, where the red encrusting algae dominate; among them, *Corallina officinalis*; **c, d** – *Laminaria hyperborea* with epiphytes constituted of annual filamentous algae and bryozoa colonies; **e** – shallow water zone occupied by association with *Fucus vesiculosus*; **f** – *Strongylocentrotus droebachiensis* population outside the channel, found predominantly in the strong current in the central part (Photo: A. Teacă).

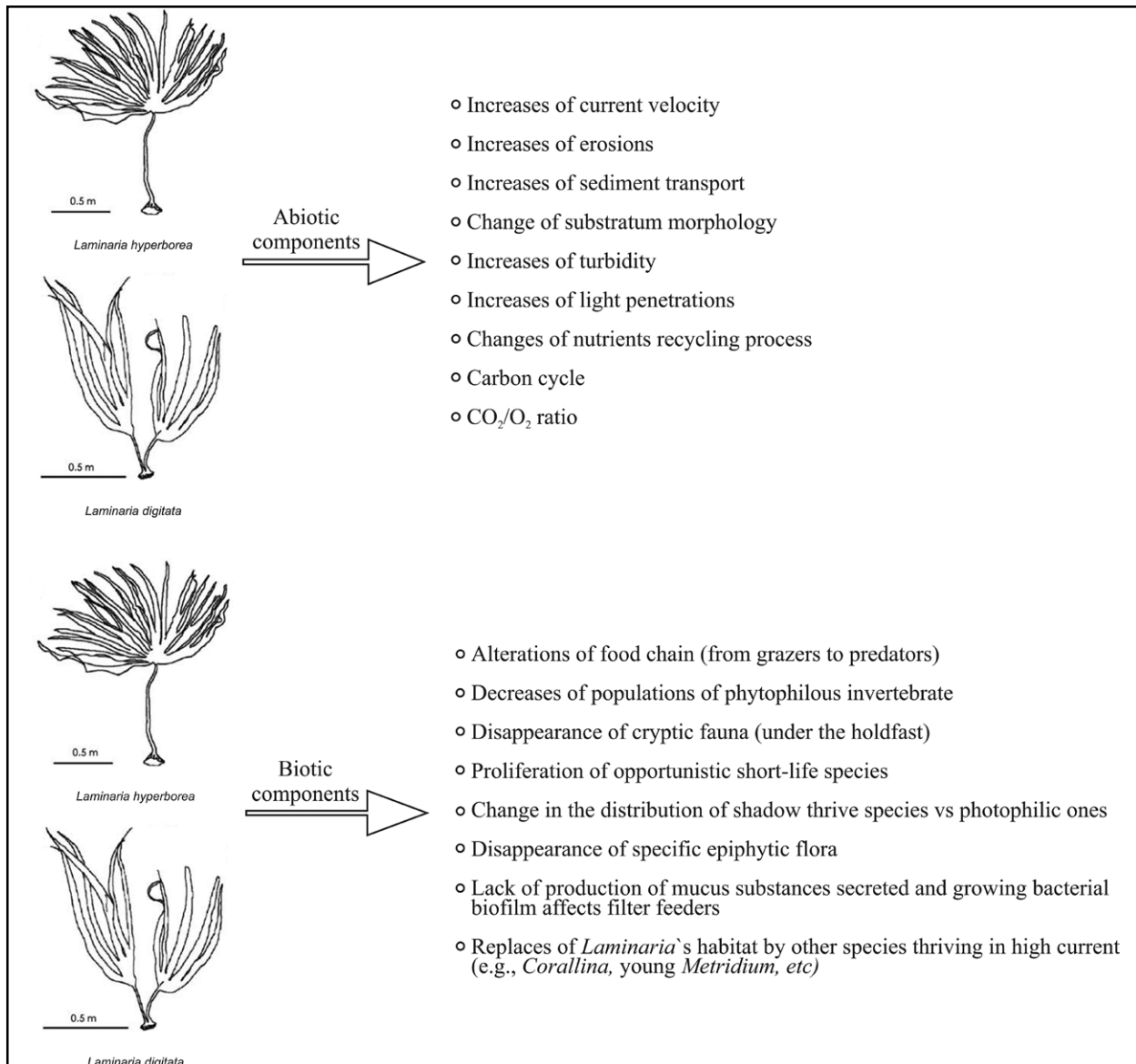


Fig. 14. Schematic representation of ecological consequences of *Laminaria*'s removal on biotic and abiotic components (original).

CONCLUSIONS

The results showed that the biotic community in Hopavågen inlet is highly diverse and dynamic due to strong interaction with the physical factors within the bay. In May and August, a total number of 30 taxa of macroinvertebrates and 15 species of macrophytes distributed in six distinct phytocoenosis, were identified.

The most striking communities, from the point of view of abundance and distribution, were *Laminaria* and *Metridium dianthus*, which seem to be best adapted to strong currents, as well as space competition. The shift from the explosive population abundance of macrophytes and benthic communities, in spring, to the offset of vegetation and diminishing in number of many benthic organisms, in summer, with changing of environmental conditions (increase of water temperature and of freshwater

inflow), was highlighted. The biodiversity and complex ecological interactions of species presented in the paper give evidence of a complex architecture of the ecosystem in terms of compositional structure and functions.

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REFERENCES

- ALVSVAG, M.D., (2017). Mapping of a seagrass habitat in Hopavågen, Sør-Trøndelag, with the use of an Autonomous Surface Vehicle combined with optical techniques. Norwegian University of Science and Technology, Department of Biology, 1-58.
- BALCHEN, J.G., (1971). Tilbakekoplet styring av fisk. *NTH, Inst.regul.tekn. Tekn. Notat* **13**:1-7.
- BALCHEN, J.G., (1979). Modelling, prediction and control of fish behaviour, 99-146 In: Leondes, C.T. (ed.): Control of dynamic systems. Academic Press, New York, 360 p.
- BATES, C.R., WHITHEAD, E.J., (2001). ECHOpus Measurements in Hopavågen Bay, Norway. The Oceanography Society, Biennial Scientific Meeting.
- HARDER, L.D., HURD, L.C., SPECK, T., (2006). Comparison of mechanical properties of four large, wave-exposed seaweeds. *American Journal of Botany* **93**(10): 1426-1322.
- HIMMELMAN, J.H., HAMEL, J.R., (1993). Diet, behavior and reproduction of the whelk *Buccinum undatum* in the northern Gulf of St. Lawrence, eastern Canada. *Marine Biology* **116**(3): 423-430.
- IMRIE, D.W., MCCROHAN, C.R., HAWKINS, S. J. (1990). Feeding behavior in *Littorina littorea*: a study of the effects of ingestive conditioning and previous dietary history on food preference and rates of consumption. *Hydrobiologia* **193**(1): 191-198. DOI10.1007/BF00028076
- KELLY, E., (ED.), (2005). The role of kelp in the marine environment. *Irish Wildlife Manuals*, **17**. National Parks and Wildlife Service, Department of Environment, Heritage and Local Government, Dublin, Ireland. 1-123. ISSN 1393 – 6670.
- KRAUFVELIN, P., CHRISTIE, H., OLSEN, M., (2002). Littoral macrofauna (secondary) responses to experimental nutrient addition to rocky shore mesocosms and a coastal lagoon. *Hydrobiologia* **484**: 149-166.
- MANGE, M.A., MAURER, H.F.W., (1992). Heavy minerals in colour. Ed. Chapman & Hall, London, 147.
- MARION, P., VAN, (1996). Ecological studies in Hopavågen, a landlocked bay at Agdenes, Sør-Trøndelag, Norway. *Gunneria* **71**: 1-39. ISBN 82-7126-508-3, ISSN 0332-8554.
- NELSON, M.L., CRAIG, S.F., (2011). Role of the sea anemone *Metridium senile* in structuring a developing subtidal fouling community. *Mar Ecol Prog Ser*, Vol. **421**: 139–149.
- PARFENOFF, A., POMEROL, C.H., TOURENO, J., (1970). Les mineraux en grains; methods d'etude et determination. Paris: Masson, 578 p.
- PAUL, M., (2014). Evaluation of the use of surrogate *Laminaria digitata* in eco-hydraulic laboratory experiments. *Journal of Hydrodynamics*, **26**(3): 374-383. DOI: 10.1016/S1001-6058(14)60042-1
- PAUL, M., HENRY, Y.T.-P., THOMAS, E.R., (2014). Geometrical and mechanical properties of four species of northern European brown macroalgae. *Coastal Engineering* **84**: 73–80. <http://dx.doi.org/10.1016/j.coastaleng.2013.11.007>.
- RASMUSSEN, A.D., BANTA, G.T., ANDERSEN, O., (1998). Effects of bioturbation by the lugworm *Arenicola marina* on cadmium uptake and distribution in sandy sediments. *Mar Ecol Prog Ser.* **164**: 179-188.
- TAIT, W. L., (2010). Primary production of intertidal marine macroalgae: factors influencing primary production over wide spatial and temporal scales: a thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy at the University of Canterbury, New Zealand, 255 p.
- WATSON, D.C., NORTON, T.A., (1985). Dietary preferences of the common periwinkle, *Littorina littorea* (L.). *Journal of Experimental Marine Biology and Ecology* **88**(3): 193-211.
- WOOLMINGTON, A.D., DAVENPORT, J., (1983). pH and PO₂ levels beneath marine macrofouling organisms. *J Exp Mar Biol Ecol*, Vol. **66**: 113-124.
- WoRMS EDITORIAL BOARD (2017). World Register of Marine Species. Available from <http://www.marinespecies.org> at VLIZ. Accessed 2017-12-27. doi:10.14284/170
- www.GoogleEarthPro.com

