Abundanz und Verteilung von Chaetognathen in der Arktis

Bachelorarbeit

Im Studienfach Biologie

FB Biologie/Chemie der Universität Bremen

Vorgelegt von

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Contents

Summary

The present thesis investigated the abundance and distribution of chaetognaths along a transect from the Barents Shelf to the Sophia Basin at approximately 81° N. Abundances under the sea-ice were compared with those in the water column down to 500 m depth. Chaetognaths from zooplankton samples taken at three stations were identified to species level and measured. *Eukrohnia hamata* specimens were classified into maturity stages. Furthermore the dry mass as well as C:N ratios were obtained for a selection of specimen to estimate the biomass and elemental composition of chaetognath ins the study area.

Abundances of up to 1.9 individuals per m^3 were encountered in the water column, constituting a biomass greater 0.328 mg/m^3. At almost all stations higher abundances were found under the ice than in the water column. The density of chaetognaths decreased when descending to deeper water layers. Abundance and biomass of chaetognaths was higher in the deep-sea basin than on the shelf. *Eukrohnia hamata* was the dominant species encountered. *Parasagitta elegans* was found in highest concentrations on the shelf. *Pseudosagitta maxima* was rarely encountered. Juvenile chaetognaths populated the upper 200 m of the water column. Mature *Eukrohnia hamata* were not discovered. Eukrohnia hamata specimens had a mean C:N ratio of 4.7, while Pseudosagitta maxima had a mean C:N ratio of 3.8.

The results of the present thesis are in agreement with distributions published for the Arctic Ocean. High abundances under the sea-ice confirm its importance for chaetognaths in the Arctic. The on-going sea-ice decline could have a great impact on the composition of chaetognaths in the Arctic Ocean.

Zusammenfassung

Im Rahmen dieser Bachelorarbeit wurde die Abundanz und Verteilung von Chaetognathen auf einem Transsekt entlang des 81. Breitengrades vom Barents Schelf zum Sophia Becken untersucht. Die Zusammensetzung unter dem Meereis wurde mit jener in der Wassersäule, bis zu einer Tiefe von 500 m, verglichen. Hierzu wurden Chaetognathen aus Zooplankton-Proben von drei Stationen auf Art-Niveau bestimmt, vermessen sowie die Reifegrade von *Eukrohnia hamata* bestimmt. Zudem wurde für einige Exemplare Trockengewichte ermittelt und das C/N-Verhältnis bestimmt um die Biomasse und biochemische Zusammensetzung im Untersuchungsgebiet zu schätzen.

Zum Zeitpunkt der Untersuchung waren Chaetognathen mit bis zu 1.9 Individuen pro m^3 vertreten in der Wassersäule mit einer Biomasse größer 0.328 mg/m^3. Für fast alle Stationen wurden höhere Abundanzen unter dem Eis als in der Wassersäule gefunden. Zudem nahm der Bestand in tieferen Wasserschichten ab. Die Abundanz und Biomasse von Chaetognathen war im Becken höher als auf dem Schelf. *Eukrohnia hamata* war die am häufigsten vorkommende Art. *Parasagitta elegans* war vor allem auf dem Schelf vertreten. *Pseudosagitta maxima* wurde nur vereinzelt gefunden. Juvenile Chaetognathen waren in den oberen 200 m der Wassersäule konzentriert. Es wurden keine reifen *Eukrohnia hamata* gefunden. Das mittlere C/N-Verhältnis von *Eukrohnia hamata* betrug 4.7, das von *Pseudosagitta maxima* 3.8.

Die Ergebnisse dieser Arbeit stimmen mit den von anderen Autoren beobachteten Verteilungsmustern für Chaetognathen im Arktischen Ozean überein. Hohe Abundanzen unter dem Meereis bestätigen die Wichtigkeit dieses Habitats für Chaetognathen. Dies ist vor allem im Hinblick auf den fortschreitenden Rückgang der Meereisfläche erwähnenswert.

1 Introduction

1.1 The Arctic Ocean

The Arctic marine realm is located between 66° N and 90° N, north of the Arctic Circle (66° 34‘ N). The Arctic Ocean, as the polar oceans in general, is a unique environment. It is defined as the smallest and shallowest world ocean and is composed of a deep central basin, which is enclosed by shallow shelves (see Figure 1). Surrounded by land, it receives limited exchange with the adjacent oceans, the Atlantic and the Pacific. Due to the spherical shape and inclination axis of the Earth, the Arctic experiences low exposure to solar energy and is characterised by high seasonality in light conditions. This leads to month-long periods of polar night in winter and midnight sun during summer. The consequences are low temperatures and year-round sea-ice coverage in higher latitudes (Herman 1989).

The Arctic shelves take in 10% of the global river runoff and are therefor highly productive regions (Herman 1989). On the other hand, the offshore deep central basins are considered less productive, as they are permanently ice-covered (Sakshaug 2004), though recent studies have proven, that there is high productivity by ice algae, supporting a vivid metazoan community (Fernández-Méndez et al. 2015; David 2015).

The Lomonosov Ridge subdivides the central Arctic Ocean into two basins: the Amerasian and Eurasian Basins (Jakobsson et al. 2003).The Eurasian Basin reaches bottom depths greater than 4000 m and in turn is divided into the Amundsen and Nansen Basin by the Gakkel Ridge. These basins are characterised by the inflow of warm Atlantic waters through the Fram Strait. These waters are high in salinity and are moreover phosphate- and nitrate-rich (Rudels et al. 2013). In the Eurasian Arctic, the Atlantic Waters are located in the layer between approximately 100-150 to 900-1000 m. The temperatures of this layer are near 0 °C and the salinities between 34,800-34,900 ppm (Timofeev 1998).

The Nansen Basin is the area in which the main re-circulation of the Atlantic Water from the Fram Strait branch takes place. The Barents Sea branch meanwhile flows eastwards to the Laptev Sea where it flows into the Amundsen Basin (Rudels et al. 2013). The Transpolar Drift is a large ocean surface current which transports sea ice

form The Laptev and East Siberian Sea towards the Fram Strait crossing the central Arctic (Mysak 2001).

Whereas the Arctic Ocean is permanently sea-ice covered in the centre, the marginal seas are only seasonally ice-covered (Horner et al. 1992). The sea ice is formed in winter along the shelves. A notable portion of marginal sea ice is transported out of the Arctic Ocean through the Fram Strait (Kwok 2004).

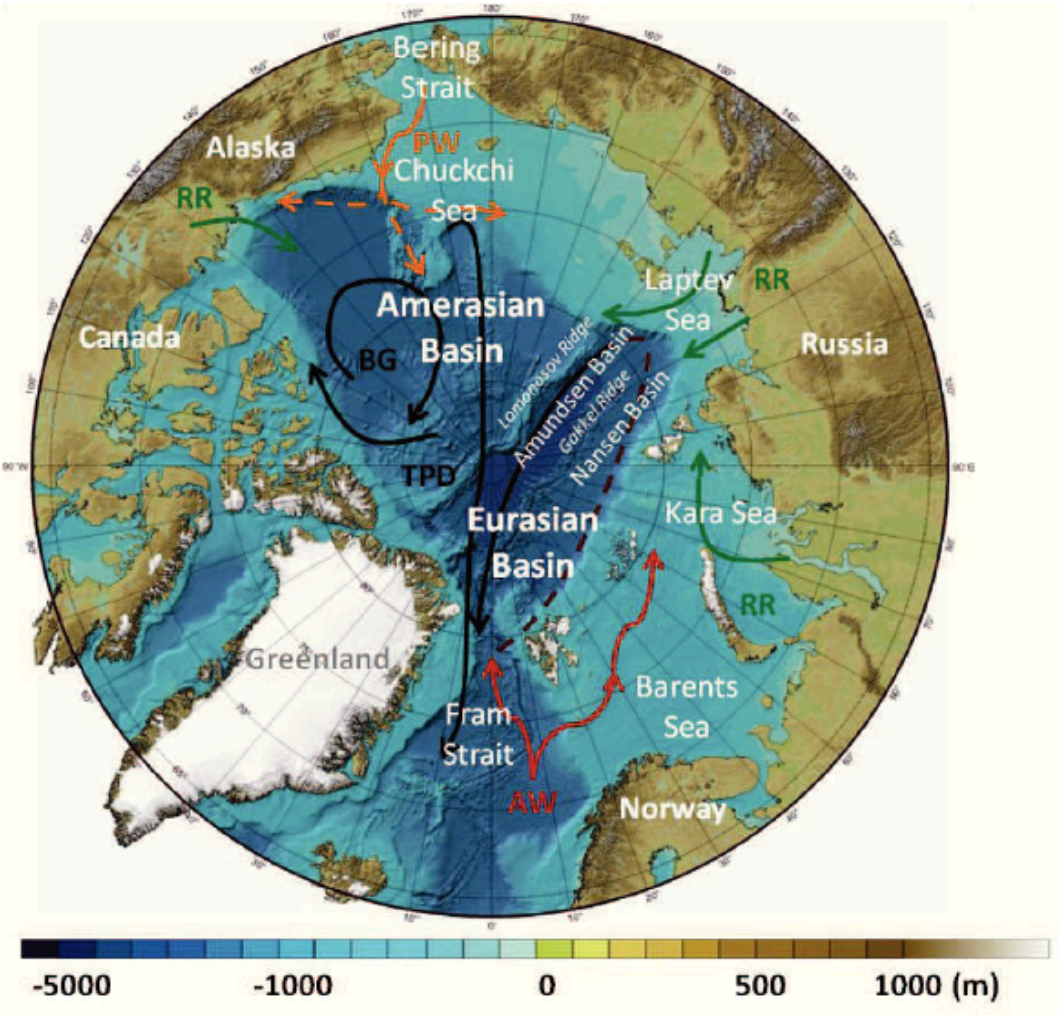


Figure 1 – Overview of the Arctic Ocean and its bathymetry with an outline of surface waters circulation. Red lines indicate Atlantic Waters (AW). Orange lines represent Pacific Waters (PW). Black lines represent cold, less saline polar water currents (TPD – Transpolar Drift, BG – Beaufort Gyre). Green lines visualise river runoff inflow (RR). The dashed line indicates the area where polar water is formed (Fernández-Méndez 2014).

1.2 Chaetognaths

Chaetognaths constitute a small phylum of approximately 150 marine species worldwide (Kapp 2004). Chaetognaths are gelatinous zooplankton, ranging from 2-120 mm in length. All species are active predators, grasping their prey with two sets of rigid hooks located at the sides of the head. The name of the phylum is derived from these hooks ("Chaeto"-"gnaths"="bristle"-"jaws"). Some species are known to inject venom into their prey before indulging it (Casanova 1999). Comprising 5-15 % of the global zooplankton biomass (Longhurst 1985) and preying mainly on copepods (Kruse et al. 2010a), chaetognaths can play an important role in pelagic food webs.

1.2.1 Morphology

A general body plan for chaetognaths is illustrated in Figure 2. The body structure is simple, being formed by the head, trunk and a well distinguishable tail, which is delimited from the trunk by a septum. One to two pairs of lateral fins as well as a tail fin qualify chaetognaths for being very good and fast swimmers. The transparency of chaetognaths varies for different species from translucent to semi-opaque. Some species are partially pigmented (Bohatá 2011). Bioluminescence for two species been reported in recent studies (Thuesen et al. 2010). The head is equipped with a vestibular organ, two sets of rigid hooks and one or two rows of teeth (Casanova 1999). Intestine and female gonads (ovaries and seminal receptacles) lie in the trunk whereas the male gonads (testes and seminal vesicles) are situated in the tail (Alvariño 1990a).

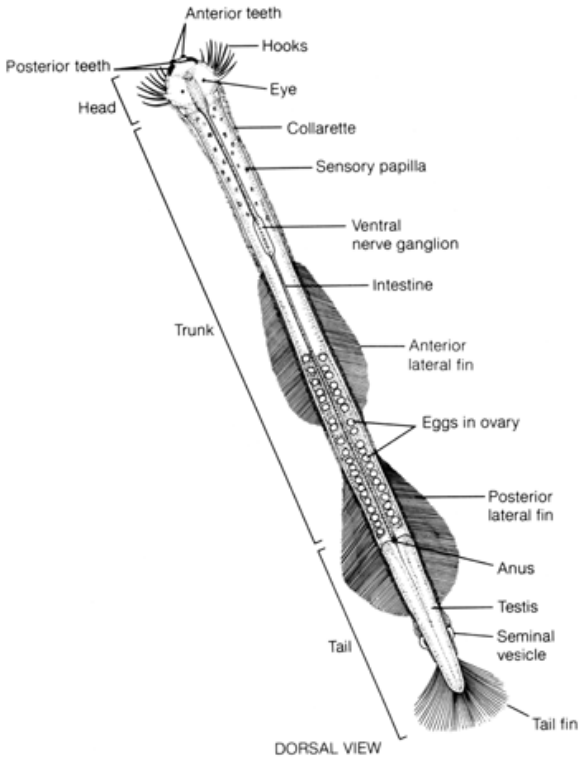


Figure 2 – Illustration of the general anatomy of chaetognaths. The body is subdivided in head, trunk and tail. Ovaries are situated in the posterior part of the trunk. Testes and seminal vesicals make up the contents of the tail. One or two pairs of lateral fins and a tail fin enable chaetognaths to swim. The head is equipped with one or two rows of teeth and its eponymous hooks. Due to the transparency of the body, the intestine is well distinguishable. The ventral ganglion can be found in the anterior part of the trunk. Some species display a collarette with thicker tissue in the neck region or over the entire body. Sensory papillae are distributed along the body (https://www.gwu.edu/~darwin/BiSc151/Ecdy/Ecdysozoa.html)

1.2.2 Life Cycle

Chaetognaths are protandrous hermaphrodites. Male gonads develop earlier than female gonads (Alvariño 1990a). Chaetognaths usually perform cross-fertilisation, though self-fertilisation has also been observed, but seems less successful (Alvariño 1990b). Eggs are laid freely in the water except for *Eukrohnia* species, which carry two gelatinous egg sacs, or marsupia, in which they breed the eggs and newly hatched “larvae’’. The term “larva” is inappropriate, as chaetognaths do not perform metamorphosis, but is used by several authors since morphological changes are significant in early life stages. Depending on the species and environmental factors such as temperature, eggs generally hatch after 2-3 days. Young chaetognaths are subject to allometric changes while growing. The tail proportion of the body for instance, or size of the ventral ganglion, is larger in juveniles than in adults. Also the number of teeth an hooks changes during maturation (Casanova 1999).

Mature specimens move to deeper water layers for spawning whereas juveniles and younger adults remain in the surface layers where they encounter better feeding conditions (Hagen 1999).

1.2.3 Abundance and Distribution

1.2.3.1 Geographic Distribution

Some chaetognath species are excellent indicators of water masses as their occurrence is closely related to environmental variables. *Eukrohnia hamata* for instance is adapted to cold waters. Chaetognaths can be found in all marine habitats worldwide at all depths. The main geographic distribution factor is water temperature (Casanova 1999). Other hydrological factors such as salinity, oxygen concentration and pressure which affect mortality and birth rates in chaetognaths and zooplankton overall are assumed to play a less important role on abundance (Cheney 1985).

1.2.3.2 Vertical Distribution

Vertical distribution of chaetognaths is affected by temperature and light intensity (Casanova 1999). Furthermore many chaetognath species are known to undergo ontogenetic migrations, moving to deeper layers for spawning (Hagen 1999). Juveniles in the contrary are found mainly in the surface layers.

Recent studies have strengthened the hypothesis that chaetognath distribution is linked to the occurrence of copepods its major prey, or krill (Marazzo and Nogueira 1996; David et al. 2016).

There is little knowledge about chaetognath abundance at the underside of the sea-ice due to limited gear for fishing under the ice. (David 2015) found a lower abundance of chaetognaths at the sea-ice underside than in the water column (0-500m) in Antarctic winter.

1.2.4 Feeding ecology

Comprising 5-15% of global zooplankton biomass and 30% of that of copepods, chaetognaths can play an important role in marine food webs (Casanova 1999; Casanova et al. 2012). Major prey are copepods (Kruse et al. 2010a); (Sameoto 1987), which create a distinct flow field in the water (Bundy and Paffenhöfer 1996; Jiang and Osborn 2004). This flow field can be detected by chaetognaths via sensory hairs (NEWBURY 1972; FEIGENBAUM and REEVE 1977). Also other organisms such euphausiids, amphipods, diatoms, ciliates, medusa, and even chaetognaths are

fed upon (Terazaki 1998). Though chaetognaths are considered to be carnivore, green detritus has been discovered in gut contents of *Parasagitta elegans*. *Pseudosagitta maxima* and *Eukrohnia hamata* have been observed ingesting green detritus in the Canadian Arctic, suggesting supplemental detritivorous and/or omnivorous feeding (Grigor et al. 2014a).

(Casanova et al. 2012) assumes, that chaetognaths feed primarily on dissolved and fine particulate organic matter and encourages to reinvestigate the role of chaetognaths in the food web. Chaetognaths in return are fed upon by a variety of organisms including chaetognaths, amphipods, jellyfish and fish (Feigenbaum 1991). Furthermore, by producing large and fast-sinking fecal pellets, chaetognaths can play a significant component in the biological carbon pump (Giesecke et al. 2009).

1.3 Chaetognaths in the Arctic Ocean

The three major chaetognaths found in the Central Arctic are *Parasagitta*, *Eukrohnia hamata* and *Pseudosagitta maxima.* They contribute substantially to the Arctic zooplankton biomass (Grigor et al. 2014b). The species are introduced in more detail in the following subsections. *Heterokrohnia involucrum* is found in bathypelagic realms of the Central Arctic (Kosobokova et al. 2010) and the presence of *Eukrohnia bathypelagica* has been reported for the Nansen Basin, though with a far lower abundance than the other chaetognath species (Mumm 1993).

1.3.1 Parasagitta elegans

P. elegans is a species found in Arctic and Subarctic regions (Kotori 1999). *P, elegans* dominates the chaetognath community in Arctic shelf seas and is considered a neritic expatriate when found in the waters of the deep central basins (Kosobokova et al. 2010),(Grigor et al. 2014b). There are three known subspecies: *P. elegans elegans, P. elegans arctica and P. elegans baltica. P. elegans* grows up to 45 mm in length (ARCODIV). The life cycle of *P. elegans* varies with its distribution range (Grigor et al. 2014b). Environmental factors such as temperature and food availability could have an impact on this variation (Terazaki 2004). Whereas specimens froms the Canadian Arctic have longer life spans with 0.5 generations per year, specimens from lower latitudes may have shorter lifespans with 5 to 6 generations per year (Russel 1932; Dunbar 1962). *P. elegans* is believed to reproduce at greater depths, though its eggs hatch in the surface layer (Hagen 1985). For a Fjord of Svalbard a 3-year life span was reported, with the months May and June marking the main

spawning season. The youngest specimens were located near the surface in these months, probably due to better feeding opportunities. In winter all cohorts had migrated to deeper layers suggesting seasonal migrations following the distribution of overwintering copepods (Grigor et al. 2014b).

P. elegans is considered to be a heterogeneous feeder, though its major prey are copepods. Chaetognaths, ostracods, larval stages of different crustaceans, dinoflagellates and even green detritus are only a fraction of contents found in its gut (Falkenhaug 1991; Terazaki 1998; Grigor et al. 2014b).

1.3.2 Eukrohnia hamata

E. hamata reaches up to 45 mm in length. It has a worldwide distribution and is found in all depths. It exhibits tropical submergence, inasmuch it descends to meso- to bathypelagic depths in equatorial and subtropical zones (Timofeev 1998; Casanova 1999). Its specific characteristic, as for all *Eukrohnia* species, are the brood pouches. It develops at maturity in which the eggs are bred until the young specimens hatch and grow (see Figure 3) (Dawson 1967).

In the Arctic *E. hamata* is found in epi- to bathypelagic depths, mostly offshore (Kosobokova et al. 2010). There exist only a small number of reports on its reproduction in Arctic regions. Immature specimens (3-22 mm length) were dominant in the surface layers near Northwest of Franz-Josef-Land. Specimens greater than 26 mm in length with more or less advanced gonad development or even carrying marsupia were found in depths greater 700 m. This vertical distribution also applies for the Antarctic and is an indicator of spawning migration (Richter 1994; Hagen 1999). (Timofeev 1998) suggests that *E. hamata* specimens mature and reproduce in the Atlantic Water layer, which is located at these depths.

E. hamata was found to feed on the same species as *P. elegans*, including green detritus, though choosing smaller prey (Terazaki 1998; Grigor et al. 2014a). In comparison also the Antarctic E. hamata seems to prefer copepods as a diet (Kruse et al. 2010b). High C:N ratios above 4 have been reported for *E. hamata* in polar regions which is explained by oil droplets found in the intestine tissue of specimens (Terazaki 1993; Kruse et al. 2010b).

Figure 3 – Picture of young specimen in marsupia in the tail region of a fully mature *E. hamata* (Dawson 1967).

1.4 Objectives

Subject of the present thesis is to investigate the abundance and distribution of chaetognaths in the Arctic Ocean north of Svalbard. The region of interest lies between Svalbard Shelf and Yermak Plateau over the southern tip of the Nansen Basin called Sophia Basin. Zooplankton samples were taken from this area on expedition PS92 with the research vessel *Polarstern* in Arctic spring 2015. The selected samples represent a transect from the Barents shelf to the Sophia Basin along approximately 81° N. The samples were taken with two different fishing gears. The SUIT is used for sampling at the sea-ice undersides, while the M-RMT samples three depth strata of the water column. Both gears have two types of meshes (Peeken 2016). In this study the finer nets with a maximum mesh size of 330 µm shall be examined. The maximum sampling depth for samples subject to distribution analysis was at 500 m.

The aim of the thesis is to find out if there are differences in abundance and distribution of chaetognaths between the depth strata in the water column. Differences between shelf, slope and deep-sea basin will also be taken into account. Furthermore the differences between distribution of chaetognaths under the ice and in the water column are to be investigated. Apart from depth, environmental factors such as temperature, sea-ice thickness and Chlorophyll a concentration shall be tested for their influence on distribution. In detail the species distribution as well as maturity and length distribution for the found species shall be examined. C:N ratios and biomass of chaetognaths for the study area will be calculated, by measuring carbon and nitrogen content of a selection of samples.

1.4.1 Hypotheses

The following hypotheses are to be verified:

1. **Abundance and biomass**: Overall abundance and biomass of chaetognaths decrease when descending from the shelf into deeper layers.
2. **Species distribution**: *P. elegans* dominates shelf regions, whereas the proportion of *E. hamata* is higher when moving towards the deep-sea basin.
3. Vertical distribution:
    a. *E. hamata* and *P. elegans* inhabit the upper layers, with juveniles generally being higher than adult specimens.
    b. Fully mature *E. hamata* are not expected to be encountered, since they are believed to migrate to depths below 500 m for spawning (Timofeev 1998).
    c. *P. maxima*, *Heterokrohnia involucrum* and *Eukrohnia bathypelagica* are found only in deeper layers of the water column.
4. **Elemental composition:** C:N ratios above 4 are expected

The results of the present thesis contribute to our knowledge about the distribution of chaetognaths in the Arctic, particularly the Sophia Basin. Since there is to date little data about zooplankton distribution under the sea-ice, the outcome may contribute significantly to reduce this gap.

2 Materials and Methods

2.1 Field Sampling

Chaetognaths were sampled during the expedition PS92 in the Nansen Basin with the research vessel (RV) *Polarstern*. Sampling was conducted in Arctic spring 2015 (15. May to 30. June 2015). Samples of the present thesis were taken with a Multiple-Opening Rectangular Midwater Trawl (M-RMT) and the Surface and Under-Ice Trawl (SUIT) on a transect from Barents Shelf to Sophia Basin (81°N) at three stations (between 16°31 and 19°91'E) (see Figure 4). An explanation of the fishing gears can be found in the following sections.

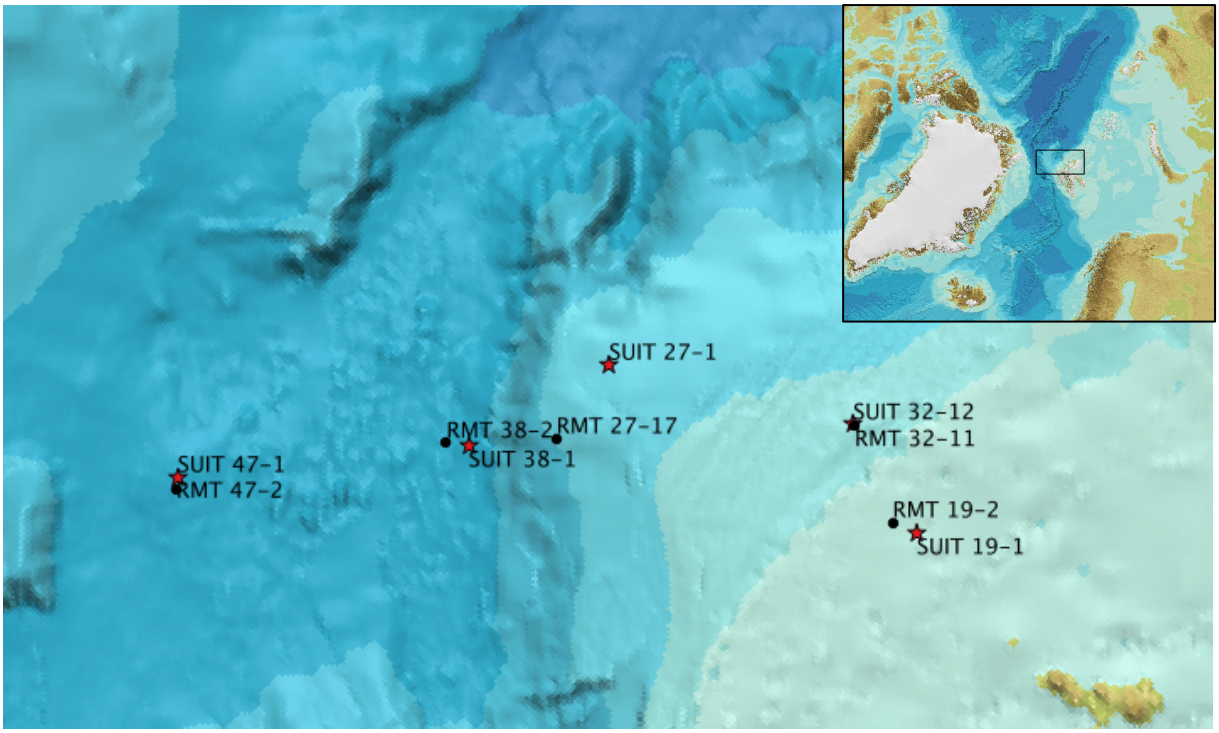


Figure 4 - Overview of region of investigated area in the Arctic as well as SUIT and M-RMT stations from which zooplankton samples originate. The area of investigation is located between the Svalbard Shelf and the Yermak Plateau. The Sophia Basin is situated in between.

Table 1 – M-RMT stations on cruise PS92 with RV *Polarstern* from which samples for the thesis were taken.

Station	Date	Start Time (UTC)	Longitude (° E)	Latitude (° N)	Bottom Depth [m]	Depth Strata [m]
19-2	27.05.15	18:16	19.737	81.033	173	0-25-50-100
27-17	01.06.15	14:47	17.1	81.292	866.2	0-50-200-300

38-2	09.06.15	17:58	16.123	81.33	2273.8	0-50-200-500

Table 2 - SUIT stations on cruise PS92 with RV *Polarstern* from which samples for the thesis were taken. SUIT stations geographically and chronologically correspond to M-RMT stations in **Table 1**.

Station	Date	Start Time (UTC)	Longitude (° E)	Latitude (° N)	Bottom Depth [m]	Depth Strata [m]
19-1	27.05.15	15:22	19.907	81.007	188.5	0-2
27-1	31.05.15	04:16	17.767	81.386	827.9	0-2
38-1	09.06.15	15:46	16.311	81.317	2249.1	0-2

Directly after hauling the catch on board, the obtained samples were split into at least two fractions with a Motoda plankton splitter (Motoda 1959). The samples were then quantitatively preserved. 50% of each catch was preserved in 4% Formaldehyde, whereas the remaining half was size fractionated and frozen at -80 °C. Chaetognaths were randomly picked from each original catch, identified to the lowest possible taxon (generally to genus level) and immediately frozen at -80 °C.
(Peeken 2016)

2.2 SUIT

The SUIT (Surface and Under-Ice Trawl) consists of a steel frame with floats attached at its top, to keep it floating at the water surface or under the sea-ice. The steel frame has a 2 x 2 m opening to which to parallel nets, each 15 m long, are fastened. The coarser net is a 7 mm half-mesh commercial shrimp net, lined with 0.3 mm mesh in its rear 3 m and covers 1.5 m of the opening width of the steel frame. The finer zooplankton net, with a mesh size of 0.3 mm, covers the remaining 0.5 m of the opening width. The SUIT is towed off with a cable of maximum 150 m length at an angle of approximately 60° to the starboard side of the ship, enabled by an asymmetric bridle. The SUIT can therefor be pulled under the sea-ice for sampling and covers the depth stratum of 0-2 m at the sea-ice underside (van Franeker and Flores 2009).

A sensor array is mounted to the SUIT frame. It contains an acoustic Doppler current profiler (ADCP), a conductivity-temperature-depth probe (CDT) with an integrated fluorometer, an altimeter, two spectral radiometers and a video camera. The ADCP is used to estimate the water inflow speed. Further more it is equipped with sensors for measuring pressure, pitch, role and heading which are used to calculate the orientation of the SUIT under water and therefor act as an indicator of the efficiency during hauling. Depth as well as temperature and salinity profiles can be obtained by means of the CTD. The fluorometer is used to estimate the chlorophyll concentration under the sea-ice and the altimeter measures the distance between the net and the sea ice underside. By means of the spectral radiometers light transmission and ice algae biomass may be measured. An observer on deck visually estimated changes in ship speed, percentage of ice concentration and any irregularities during each haul. The observer also recorded GPS waypoints when the SUIT was deployed in the water and hauled back on deck. GPS waypoint were also recorded when the SUIT entered or exited the sea ice (David et al. 2015).

2.3 M-RMT

The Multiple-Opening Rectangular Midwater Trawl (M-RMT) is a fishing gear for sampling three depth strata of the water column with a coarse and a fine mesh each. It consists of two sets of three nets respectively combined within the same frame. The finer RMT-1 nets have a mouth area of 1 m^2 and a mesh size of 330 µm. The coarser RMT-8 nets cover a mouth area of 8 m^2 with a mesh size of 4.5 mm. A CTD is attached to the RMT frame for measuring environmental parameters. The RMT is trawled behind the ship and initially all nets are closed. For sampling the opening of the nets is triggered electronically. One net of RMT-1 and RMT-8 respectively will be opened upon triggering and will collect samples from the same depth. The opening of the second sets of nets, for sampling the following depth strata simultaneously closes the previously opened nets. These steps are repeated for the third depth strata (Roe and Shale 1979; Peeken 2016)

2.4 Laboratory Methods

Samples from the finer nets of both gears M-RMT (330µm) and SUIT (300µm) were used for investigation of distributions and abundances. Zooplankton samples preserved in 4% Formaldehyde were thoroughly rinsed with tap water to minimize health effects caused through exposure to fumes. Samples containing a lot of

biomass were split into smaller fractions using a Motoda plankton splitter (Motoda 1959). In this manner random subsamples were created containing approximately 20 chaetognath specimens each.

Chaetognaths were sorted from the resulting subsample under a stereo microscope (Leica M205 C), utilizing a Bogorov dish. Specimens without a head were ignored since the head is the main characteristic for identifying the right species. Heads without bodies were identified and counted.

2.4.1 Species Identification

In total 342 individuals were classified. Specimens <8 mm were classified as juveniles and omitted from species identification due to the time consuming process.

Species identification was performed using keys from (Pierrot-Bults et al. 1988; Bone et al. 1991)

Subject of observation were therefor eye pigmentation, number and colour of hooks, number of rows of teeth, approximate number teeth, presence of a collaret, presence of gut diverticula, number of pairs of fins and their structure. Where present the number of rows of ova in the ovaries, shape and size of seminal receptacles and seminal vesicles were noted. The position of the latter was also examined. For a selection of specimens these features were documented for later analysis.

2.4.2 Measurements

Specimens were put in water and measured under a stereo microscope (Leica M205 C) coupled to a digital image analysis system (Leica Application Suite) to the nearest 0.1 mm. Subject of measurement were complete length (from the head to the tip of the tail excluding the tail fin), tail length, body width at the broadest part, head width, eye distance, ovary length, ova size and testes length. Furthermore for *Eukrohnia hamata* specimens the approximate amount of sperm load in the tail segment was estimated as percentage of tail capacity.

2.4.3 Determination of Maturity Stages

For *E. hamata* the maturity stages were estimated following the classification introduced by (Alvariño 1990a). Maturity stages and corresponding features for *E. hamata* are listed in Table 3.

Table 3 – Definition of maturity stages for *E. hamata* (Alvariño 1990a). Features indicating maturity stages are subdivided for male and femal gonads. Body lengths for maturity stages are also listed

Stage	Male gonads	Female gonads	Size [mm]
0	no signs of male or female gonads		
I	Testes as fine tubes, seminal vesicles not present	Ovaries as fine tubes	<18
II	Tail segment filled with sperm, seminal vesicles incipient to full	Ovaries longer than in previous stage	25
III	Tail segment partially discharged, seminal vesicles broken	Ovaries increasing in length, ova developing	40
IV	Tail segment discharged, region of seminal vesicles covered by a thickening of epidermis	Ovaries reaching up to 2/3 of distance from ventral ganglion; ova fully developed	

Specimens with an estimated sperm load higher than 1% were identified as stage II. Specimen with ova >0.4 mm were classified as stage III.

Table 4 – Comparison of number of specimens of *E. hamata* classified according to maturity stages with total number of *E. hamata* encountered in different depth strata.

Depth Strata [m]	Classified *E. hamata*	Total *E. hamata*
0-2	31	42
0-50	49	60
50-200	50	95
200-500	9	23

2.4.4 Dry Mass and Elemental Composition

38 specimens (28 *E. hamata*, 10 *P. maxima*) specimens, frozen at -80 °C on board, were used to analyse dry mass and elemental composition of chaetognaths. The specimens were taken from the coarser nets of SUIT (7 mm) and M-RMT (4.5 mm) from various stations at different depths throughout the Sophia Basin (see Appendix).

Specimens were thawed for approximately 15 minutes on ice in the fridge at 8 °C. After thawing total length, tail length and head width of specimens were measured under a stereo microscope (Leica M205 C) coupled to a digital image analysis system (Leica Application Suite) to the nearest 0.1 mm. Measurement of body width was not performed since the chaetognaths were bloated as a result of the freezing process. Ovary length was measured where easily distinguishable, and ontogenetic features such as seminal receptacles and vesicles were observed. Specimens were transferred to combusted and pre-weighed glass vials for further processing as described in the following sections.

Wet and dry masses were measured for 38 chaetognaths (*28 E. hamata, 10 P. maxima*). For the analysis combusted glass vials were prepared. The glass vials were weighed on Mettler AE200 balance three times each. The mean values of measurements were used for the vial weights in further calculations. Thawed specimens were put in such a separate glass vial each. By weighing the filled vials, again three times each, the mean value for the wet mass of specimens was obtained by subtracting the mean empty vial weight from the mean filled vial weight. Samples were then freeze dried for 24 hours. Afterwards vials were again weighed three times to obtain the dry mass of specimens according to the calculations performed for the wet mass.

Carbon and nitrogen content was measured for 28 specimens (18 *E. hamata*, 10 *P. maxima*). The dry mass of each sample was separately ground thoroughly in a mortar and pestle. The resulting matter was then filled into tin caps with a size of 9 x 5 mm, each tin cap holding between 0.5 and 1.0 mg of dry matter. Weighing of tin caps and contents was performed on a Mettler Toledo microbalance. The tin caps were folded into small packages with a diameter of 2 mm utilising two pincers. Folded tin caps were stored in an indexed microwell plate for further processing. Measurement of carbon content and C:N ratios itself was conducted by a technician using an elemental analyser (EuroVector EA, type EuroEA 3000) at the AWI.

2.5 Calculations and Statistical Analyses

Most of the calculation and statistical analysis as well as the visualisation of results in graphs was performed using the software R. Remaining calculations were executed in Microsoft Excel.

2.5.1 Length Predictions

31 of 220 *E. hamata* individuals preserved in Formaldehyde were damaged, such that measurement of body length was not possible. For these specimens, body length was predicted by linear regression for head width to body length relationships derived from undamaged *E. hamata*.

2.5.2 Abundances

Abundances were calculated as individuals per m^3. Here for the numbers of individuals counted in a subsample were divided by the fraction of the investigated subsample and divided by the volume of trawled water per station and net.

Trawled Volumes were kindly provided by Dr. Hauke Flores. They were calculated from ship speed, net opening and covered distance for the M-RMT using the formula introduced by (Roe et al. 1980). For the SUIT, trawled areas were calculated from the distance sampled in water, which is estimated from ADCP data, and net width (Flores et al. 2012).

2.5.3 Biomass

Linear regressions model were calculated for the relationship of body length to dry weight for *E. hamata* and *P. maxima*. Biomass [µg/m^3] was determined per station gear and net by applying the models to the measured and predicted specimen preserved in Formaldehyde and dividing the values by trawled volumes for the respective nets.

2.5.4 Carbon Content and C:N Ratios

Of the frozen samples one P. maxima and E. hamata each were lacking a head. Linear regression for tail to body length relationships separately derived for *E. hamata* and *P. maxima* were used to predict the body lengths of these specimens. Standard deviation of C and N values were checked for replicas of each specimen. A mean C µg/mg and N µg/mg drymass were calculated for each specimen. Carbon contents for E. hamata and P. maxima were calculated by multiplying the mean C µg /mg/m^3 for all representatives of each species by the previously discussed biomass. C:N ratios were calculated by dividing the overall mean C µg by the overall mean N µg for both species.

2.5.5 Vertical and Spatial Distributions

The depth strata 0-2 m, 0-50 m, 50-200 m and 200-500 m were introduced to investigate vertical distribution of chaetognaths. The depth strata roughly correspond to the SUIT net, and M-RMT nets 1-1 to 1-3. M-RMT station 19-2 lacks the deepest depth stratum and nets 1-2 and 1-3 are comprised in the 0-50 m depth stratum.

Since normal distributions for length measurements and abundances could not be achieved through transformation, significant differences in various length distributions for *Eukrohnia hamata* were evaluated with Kruskal-Wallis tests.

2.6 Possible Sources of Error

Theoretically very precise measurements can be performed with the stereo microscope (Leica M205 C) coupled to a digital image analysis system (Leica Application Suite). Nevertheless measurement values are provided to the nearest 0.1 mm to account for errors arising through the orientation of the specimen.

Chaetognaths preserved in Formaldehyde (4% final concentration, buffered with hexamine) for four months shrink up to 21%. For *E. hamata* a value of 3.67% (sd ± 2.51) was reported by (Kruse et al. 2009). The shrinkage process slows down after subsequently. Samples investigated in the present study were exposed to Formaldehyde preservation for approximately one year. All measurements may therefor underestimate original sizes of specimens. Samples for SUIT station 19-1 and 27-1 had been preserved in EtOH 70% after preservation in Formaldehyde (F4%). (Dawson 1967) reported deviations of ±0.5 mm for body lengths of chaetognaths. Samples taken for elemental and biomass analysis were bloated due to the freezing process, which may also affect body lengths.

The accuracy of the Motoda plankton splitter was investigated by (van Guelpen et al. 1982). They reported a 16% coefficient of variation for *P. elegans*.

3 Results

3.1 Abundance and Vertical Distribution

The highest abundance for both gears was encountered at SUIT station 38-1. In general abundances under-ice were higher than in the water column, except for station 19, where almost no specimens were found. Abundances per station and species are illustrated in Figure 5. For the M-RMT samples, abundance of chaetognaths was highest at stations 19-2 (1.19 ind./m^3) and 38-2 (1.06 ind./m^3). Abundance at station 27-17 was comparably low with 0.45 ind./m^3. For the SUIT samples, the overall abundance of chaetognaths was lowest at the shelf station 19-1 (0.006 ind./m^3) and highest at station 38-1 (1.6 ind./m^3).

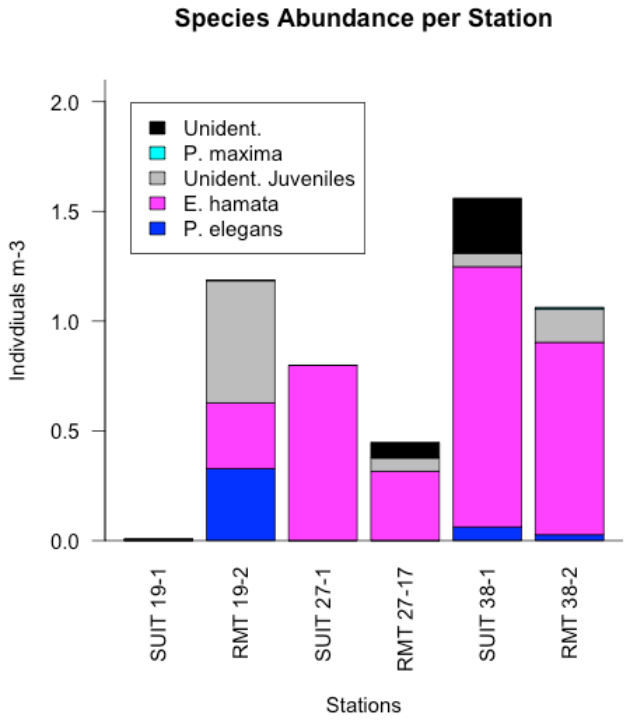


Figure 5 – Overview of species abundances summarized per station and gear. The abundances are presented as individuals per m^3. The colours indicate the abundance of each species per station. Black portions indicate unidentified chaetognaths. Grey portions indicate unidentified juvenile chaetognaths. Blue, cyan and magenta portions indicate P. elegans, E. hamata and P. maxima respectively.

The abundance of *P. elegans* was highest in the water column at station 19-2 where it represents ~28% of all chaetognaths found. In contrast, no specimens of *P. elegans* were encountered in the SUIT samples of station 19-1. At station 38 *P. elegans* represented 4% and 3% of chaetognaths in SUIT and M-RMT samples

respectively. In all other samples *P. elegans* was not present (see Figure 6). *E. hamata* was the dominant species at all stations, except for M-RMT station 19-2. The portion of *E. hamata* ranged from 25% at station 19-2 to 100% at station 19-1.

Juvenile chaetognaths, not identified to species level, were encountered in high numbers at station 19-2 where they comprised 48% of all chaetognaths. They were also present at stations 27 and 38 in lower abundances, constituting less than 15% of the chaetognath community. *P. maxima* was encountered at M-RMT stations 27-17 and 38-2 with calculated abundances of 0.003 and 0.006 ind./m^3 respectively. One individual was encountered at station 27 between 200 and 500 m depth with a body length of 12.3 mm and a head width of 1.5 mm. Gonads were not visible in this specimen. At station 38 at 50-200 m depth a head of *P. maxima* was found measuring 3.6 mm in width. Percentages for all chaetognath groups at investigated stations are illustrated in Figure 6.

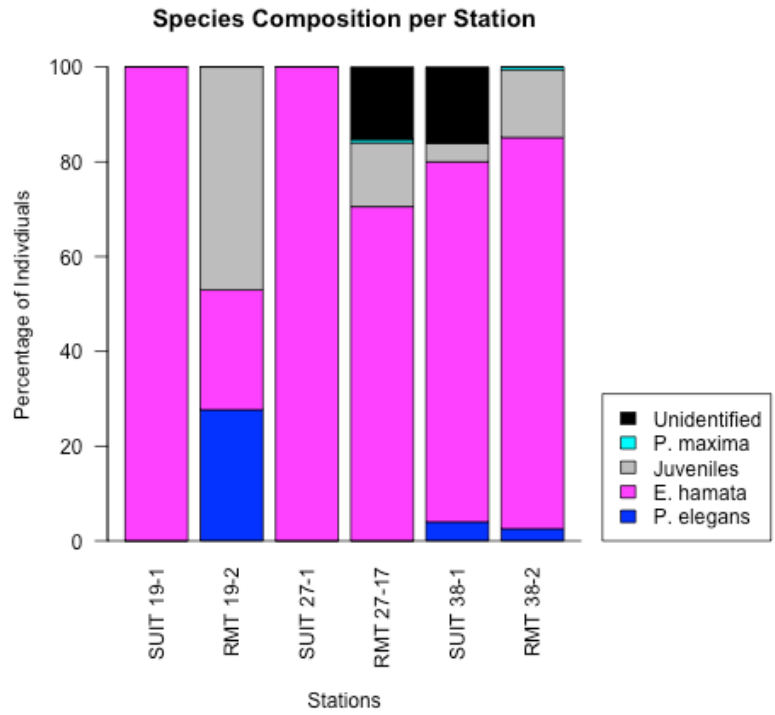


Figure 6 - Overview of species composition summarized per station and gear. Portions of each group are displayed in percentages of all chaetognaths per station. Colours indicate the percentage of each species per station. Black portions indicate unidentified chaetognaths. Grey portions indicate unidentified juvenile chaetognaths. Blue, cyan and magenta portions indicate *P. elegans, E. hamata and P. maxima* respectively.

3.1.1 Vertical Distribution

Highest abundances were found under the ice and in the 0-50 m depth layer of the water column. Lower abundances were encountered between 50 and 500 m, with the lowest abundance in the 200-500m depth strata. *E. hamata* was encountered at all depths, with highest abundances under the ice. High abundances were found in the 0-50 m depth strata of the water column, though they were significantly lower than under the ice. The abundances were the lowest between 200 and 500 m. Except for station 19-2 (see Figure 9), abundances decreased from under the ice to the deepest depth strata. *P. elegans* was only present above 200 m and only at station 38-1 under the ice. On the contrary *P. maxima* was encountered exclusively at depths below 200 m. Juvenile chaetognaths were most abundant at the surface layer of the water column on the shelf. Few juveniles were also found at station 38 under the ice and above 50 m. Vertical distributions and abundances of chaetognath species summarized for all stations are depicted in Figure 7 and Figure 8. Vertical distribution of species at each station is depicted in Figure 9.

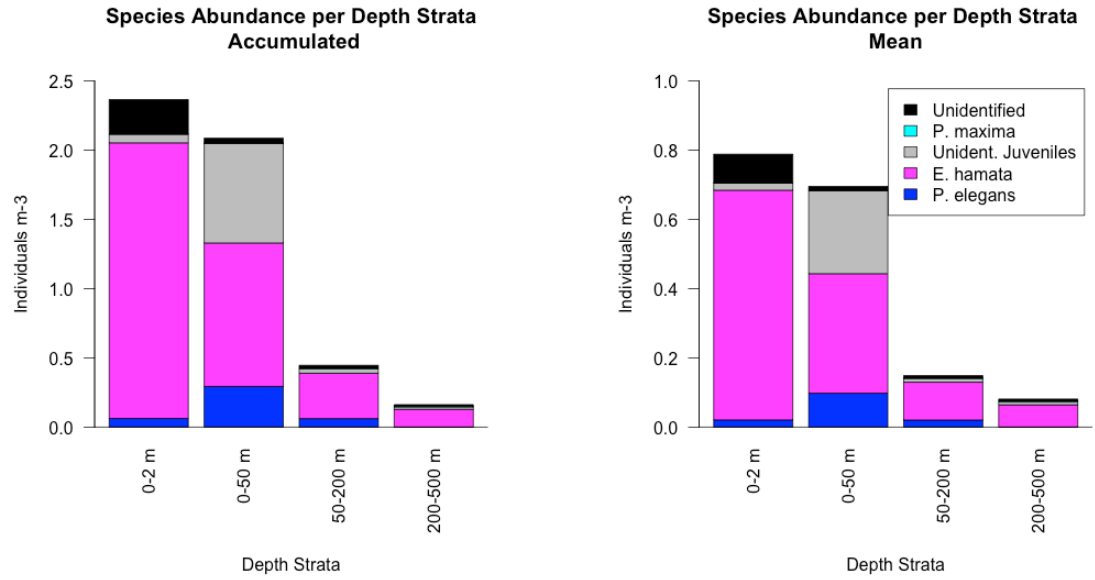


Figure 7 – Overview of species abundances for all stations and gears, grouped by depth strata. Accumulated: Abundances are summarized for all stations per depth strata. Mean: Mean abundances per depth strata for all stations are displayed. The abundances are presented as individuals per m^3. The colours indicate the abundance of each species per depth strata. Black portions indicate unidentified chaetognaths. Grey portions indicate unidentified juvenile chaetognaths. Blue, cyan and magenta portions indicate *P. elegans, E. hamata and P. maxima* respectively.

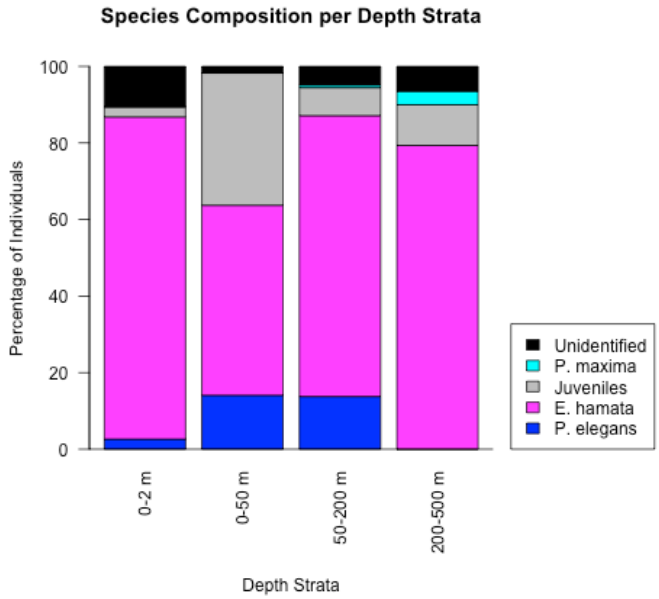


Figure 8 - Overview of species composition summarized for all gears and stations, grouped by depth strata. Portions of each group are displayed in percentages of all chaetognaths per depth strata. Colours indicate the percentage of each species per station. Black portions indicate unidentified chaetognaths, grey portions unidentified juvenile chaetognaths. Blue, cyan and magenta portions indicate *P. elegans, E. hamata and P. maxima* respectively.

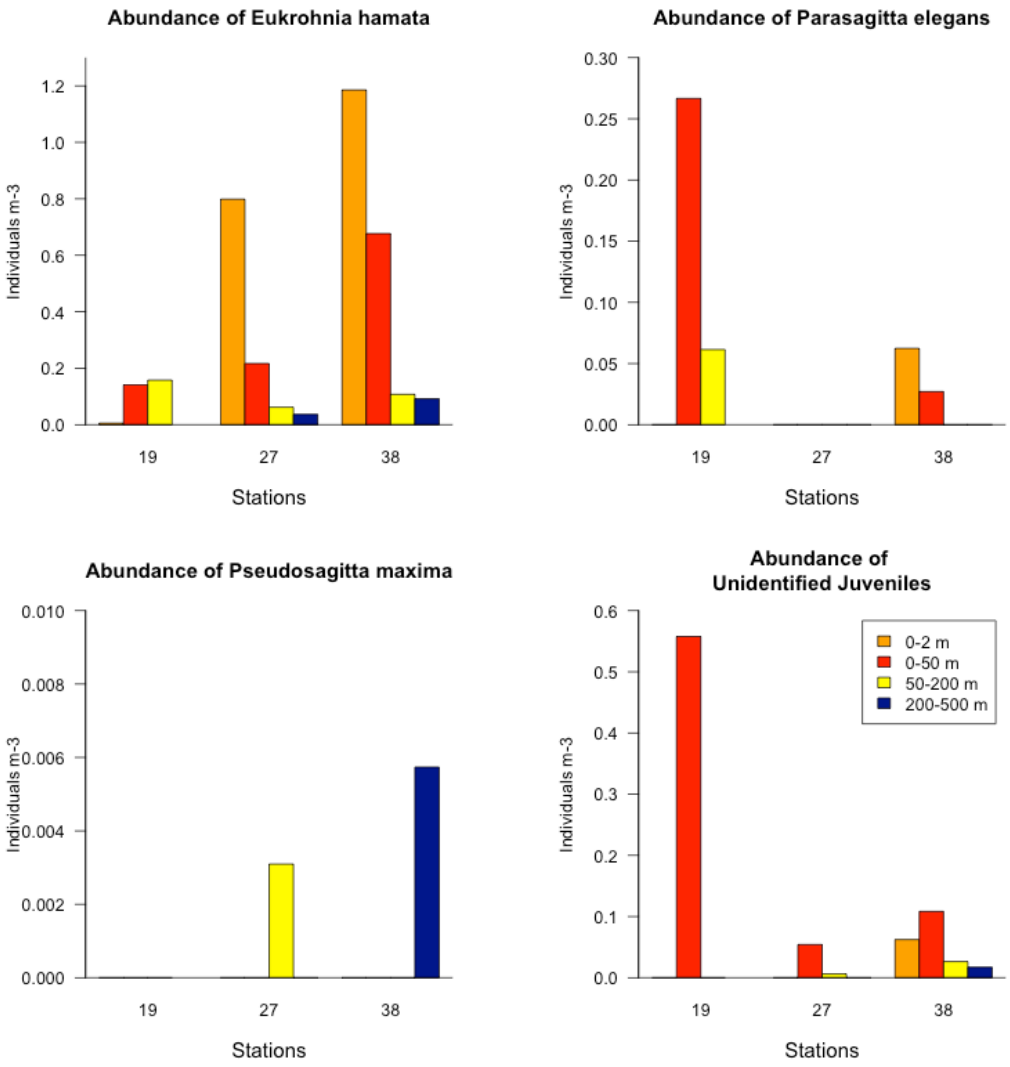


Figure 9 - Abundances of *E. hamata, P. elegans* and *P. maxima* as well as unidentified chaetognath juveniles, measured in individuals per m3, for the investigated SUIT and M-RMT stations. Separate bar plots for each afore mentioned group are displayed. Bars are grouped per station. SUIT and M-RMT hauls for each station are grouped together. The colour of the bar indicates the depth strata for which abundances are displayed. The bars are ordered from left to right by depth of sampled layers, starting at the under-ice layer and descending into deeper layers. Orange bars indicate abundances in the at 0-2 m layer (SUIT plankton net). Red, yellow and blue bars indicate abundances in the depth layers sampled with the M-RMT.

3.2 Length and Maturity Distribution

Lengths for *P. elegans* (n=35), *E. hamata* (n=220) and juveniles are visualised in Figure 10 and are described in the following.

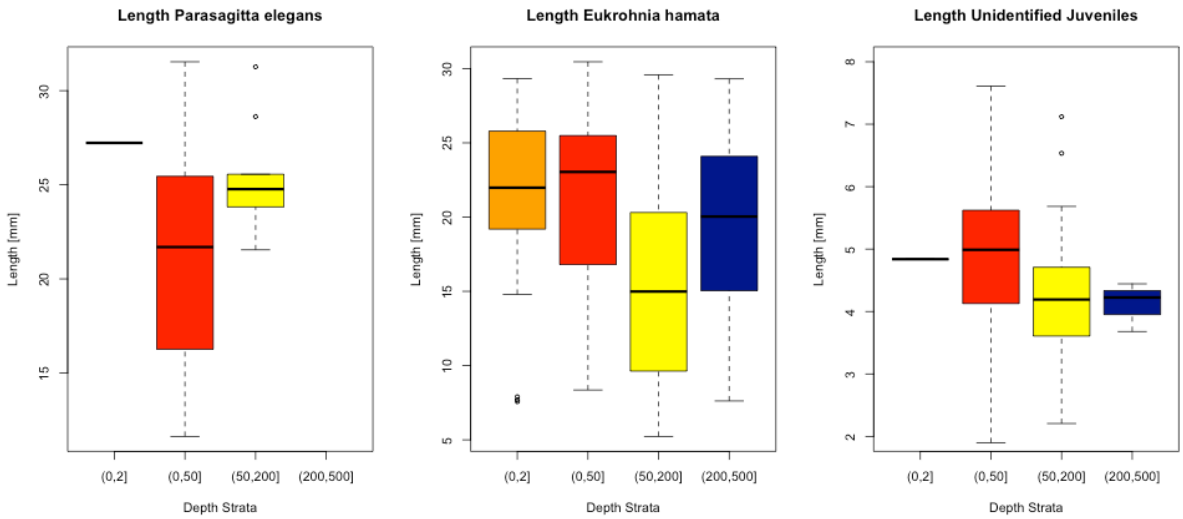


Figure 10 – Median, 1st and 3rd quartile values for body lengths of *P. maxima*, *E. hamata* and unidentified juvenile chaetognaths for all depth strata.

3.2.1 Juveniles

Juvenile chaetognaths not identified to species level (n=59) ranged between 1.9 mm and 7.6 mm length with a mean length of 4.7 mm. One juvenile was encountered at 0-2 m with a length of 4.8 mm. Juvenile chaetognaths in the depth layer 0-50 m (n=39) ranged between 1.9 mm and 7.6 mm with a mean length of 4.9 mm. Juvenile chaetognaths in the depth layer 50-200 m (n=16) ranged between 2.2 mm and 7.1 mm, with a mean length of 4.3 mm. Unidentified juveniles found lower than 200 m (n=3) had lengths between 3.7 mm and 4.4 mm.

3.2.2 Parasagitta elegans

Body lengths of encountered *P. elegans* ranged between 11.6 and 31.5 mm with a mean value of 22.5 mm (see Figure 10). *P. elegans* in the 0-50 m depth layer ranged between 11.6 mm and 31.5 mm. Specimens found in 50-200 m depth had body lengths between 21.5 mm and 31.3 mm. The single individual found under the ice was 27.2 mm long. Length distribution for 0-50 m and 50-200 m depth strata are presented in Figure 11. The proportion of ovary length to body length ranged

between 5.8% and 38.6% with a mean value of 20.5% for individuals investigated (n=18). Seminal vesicles, seminal receptacles were easily distinguishable for these specimens. Tail segments were filled with sperm. Relationships between body length and ovary length, as well as ovary length and ova size are depicted in Figure 12.

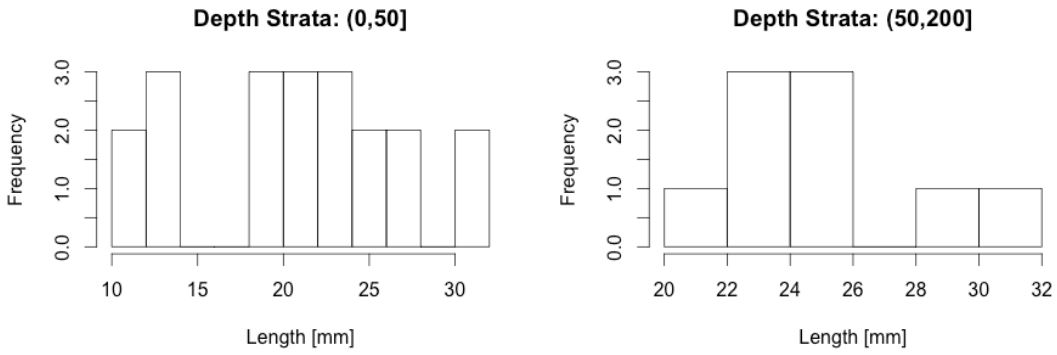


Figure 11 – Distributions of body lengths for *P. elegans* for the depth strata 0-50 m and 50-200 m.

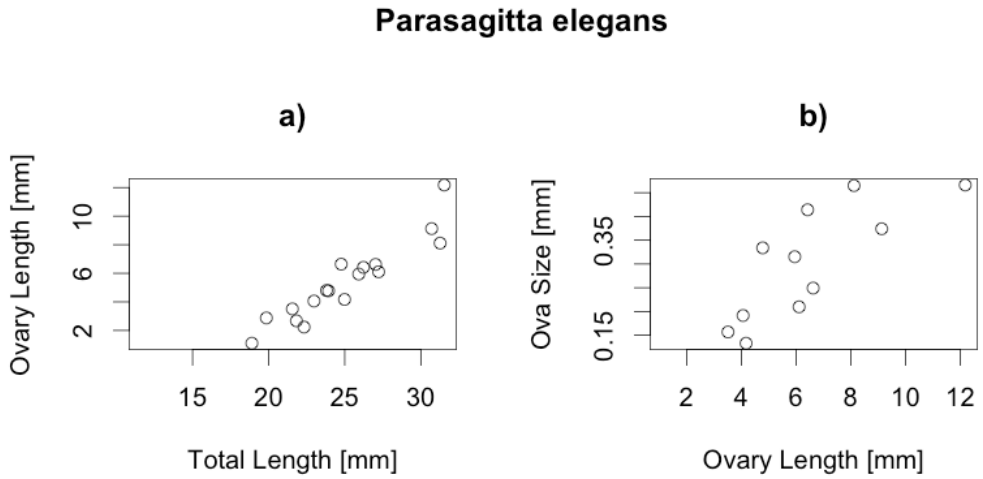


Figure 12 – Relationships between measurements for *P. elegans*. a) Relationship between body length and ovary length. b) Relationship between ovary length and ova size of *P. elegans*.

3.2.3 Eukrohnia hamata

Body lengths of *E. hamata* ranged between 5.2 and 30.5 mm. A linear relationship was encountered between head widths and body lengths of *E. hamata* (see Figure 13).

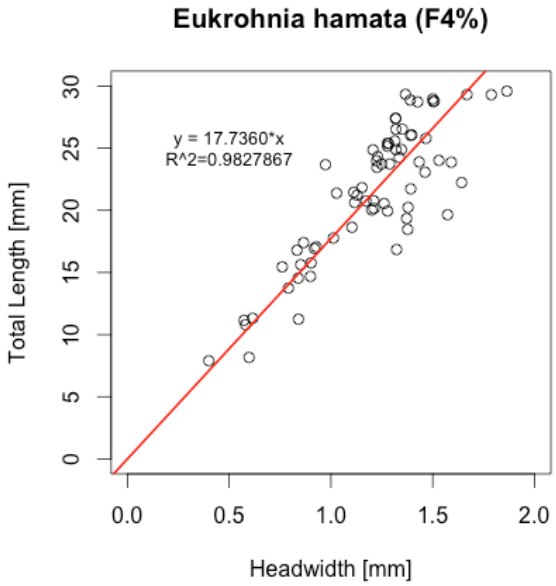


Figure 13 – Linear relationship between head width and total length of *E. hamata* specimens (n=70). Black circles indicate data points for all individuals. The red line indicates the corresponding linear model. Function and R^2 of the linear model are plotted in the graph.

Maturity stages found for *E. hamata* ranged from stage 0 to stage III. Lengths of body, ovary and testes measurements for the different stages are visualised in Figure 14. Juvenile *E. hamata* (n=41) ranged between 5.2 and 18.6 mm with a mean 9.4 mm. Lengths for Stage 1 (n=34) were between 11.7 mm and 30.5 mm with a mean value of 19.6 mm. Stage II individuals (n=63) had body lengths of 14.7 and 29.6 mm with a mean value of 23.2 mm. The only stage III individual found was 29.3 mm long. Lengths of body, ovaries, testes as well as sperm load between maturity stages were compared with Kruskal-Wallis. P-values between all groups were <0.05 and are presented in Table 5.

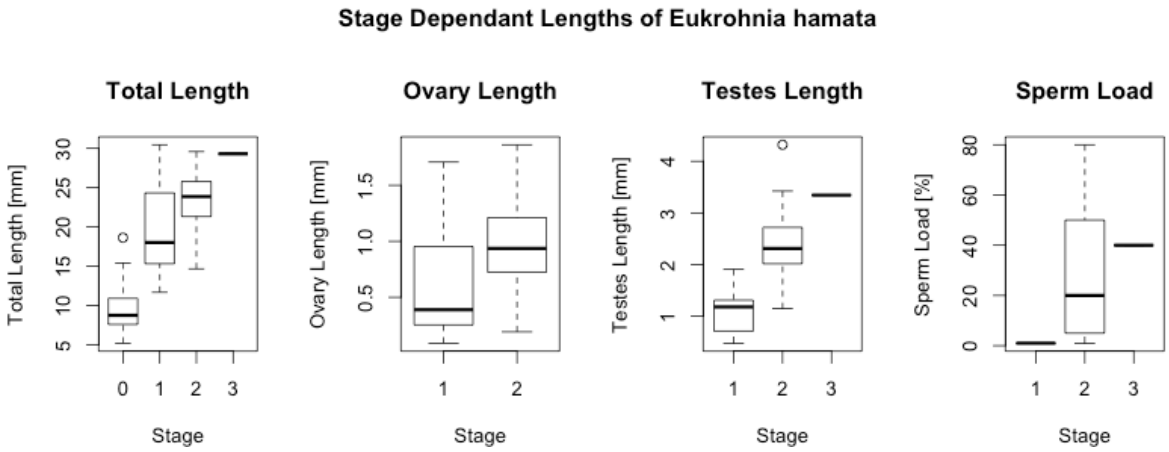


Figure 14 – Median, 1st and 3rd quartile values for body, ovary and testes lengths as well as sperm load for the maturity stages 0-III of *E. hamata*.

Table 5 – Results of Kruskal-Wallis tests comparing body, ovary and testes lengths of the maturity stages 0-III identified for *E. hamata.*

	Total Length	Ovary Length	Testes Length	Sperm Load
p-value	< 2.2e-16	0.0003745	9.853e-09	7.971e-14

Length distributions in the different depth strata for all *E. hamata*, including unclassified specimens, are visualised in Figure 15. A Kruskal-Wallis test with a post-hoc Nemenyi test was performed to estimate the degree of difference between body lengths for all depth strata. P-values were <0.05 for the comparison between 0-2 m and 50-200 m depth strata, as well as 0-50 m and 50-200 m depth strata. The results are presented in Table 6.

Table 6 – Results of a Kruskal-Wallis post-hoc Nemenyi test comparing body lengths of *E. hamata* between different depth strata. P-values indicate how significantly different the length distributions in the depth strata are. P-value for the Kruskal-Wallis test was 1.809e-07.

	(0,2]	(0,50]	(200,500]
(0,50]	1.00	-	-
(200,500]	0.58	0.64	-
(50,200]	1.9e-05	2.6e-06	0.17

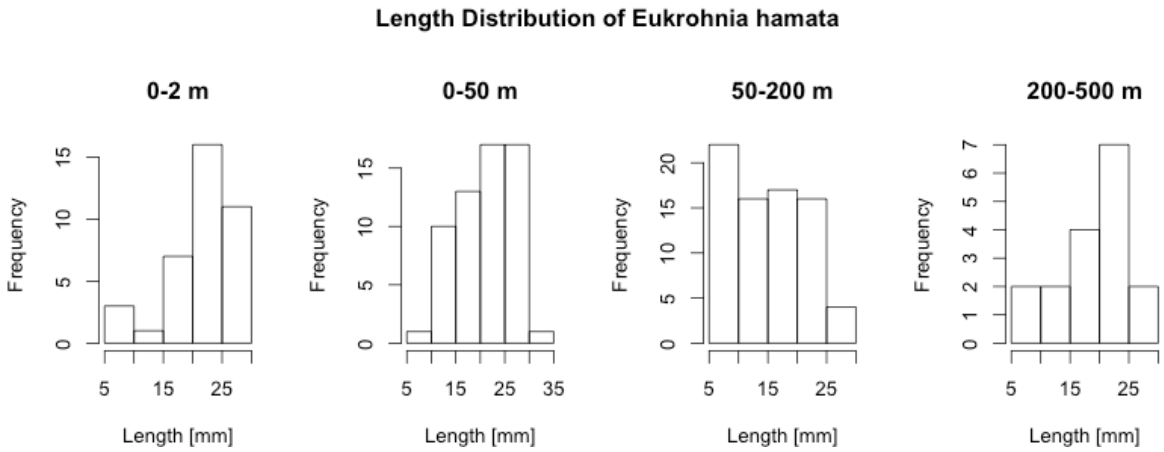


Figure 15 – Distributions of body lengths of *E. hamata* specimens subdivided by depth strata.

Portions of each stage in all depth strata are presented in Figure 16. Stage II adults were the largest group under the sea-ice and above 50 m. Stage I adults were frequent under the ice, between 0-50 and 200-500 m. Juveniles were most common between 50-200 m. For the 200-500 m depth strata less than 40% of specimens were stage classified.

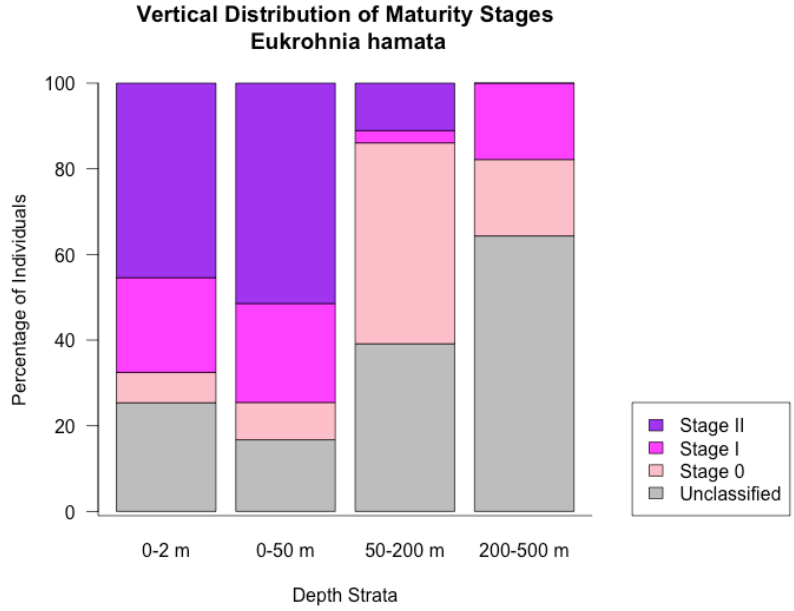


Figure 16 – Vertical distribution of maturity stages found for *E. hamata*. Colours indicate the percentage of specimens belonging to each stage in all investigated *E. hamata* for each depth strata. Grey portions indicate the percentage of E. hamata that are not stage classified.

3.3 Biomass

Linear relationships between tail length and body lengths were found for the frozen specimens of *E. hamata* and *P. maxima*. The linear regression models are depicted in Figure 17. A nonlinear relationship was found between body lengths and dry weights of *E. hamata* (see Figure 18), while no relationship was found for *P. maxima*. At station 19 the summed up biomass over all gears and nets for *E. hamata* was 0.328 mg/m^3, at station 27 0.366 mg/m^3 and at station 38 0.363 mg/m^3. Biomass data is visualised in Figure 19.

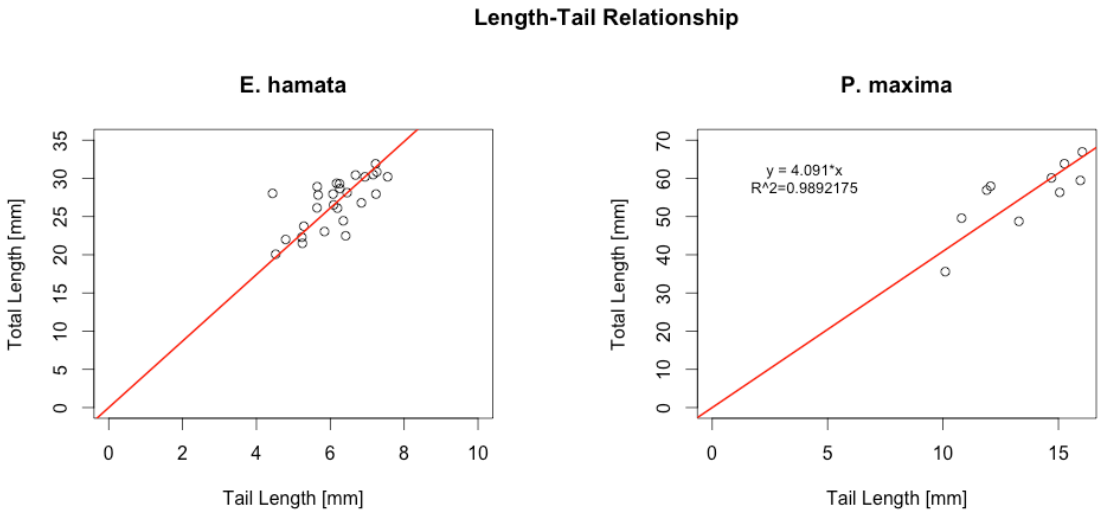
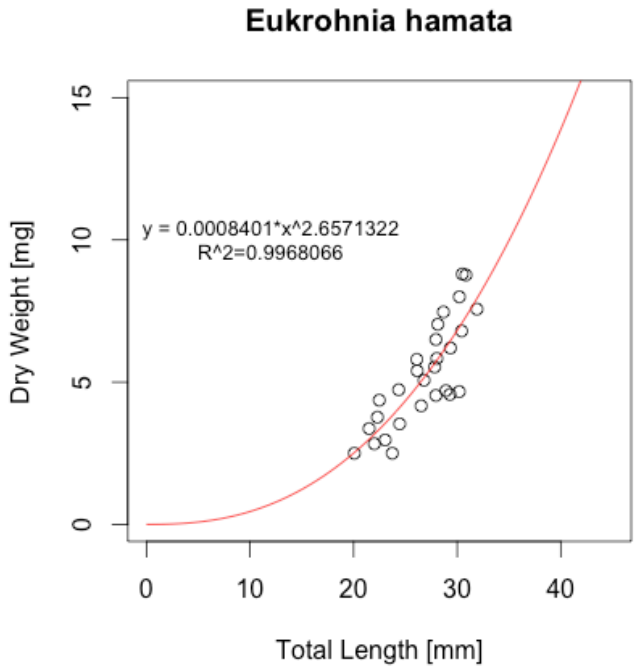


Figure 17 – Relationships between tail lengths and total length of *E. hamata* and *P. maxima*. The linear regression models were used for analysis of elemental composition and dry weight. Black circles represent data points for measured specimens. The red line indicates linear regression. Functions of the linear models and corresponding R^2 are printed in the plot.



3.4

Figure 18 – Total length vs. dry mass measured for *E. hamata*. Black circles indicate data points for individual specimens. Red line: nonlinear regression model assumed for relation between body length and dry weight for *E. hamata*. Function of the model and R^2 are printed in the plot. The nonlinear model for predicting the biomass of the quantified *E. hamata* preserved in Formaldehyde.

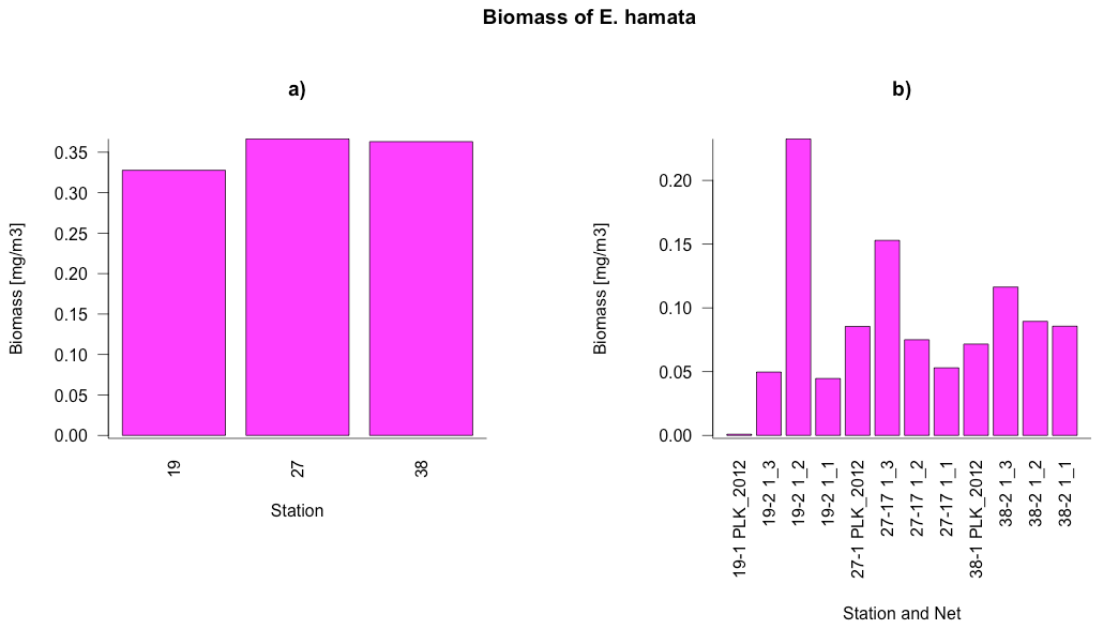


Figure 19 – Overall biomass of *E. hamata.* a) Biomass at all stations summed up for M-RMT 1 nets and SUIT plankton net. b) Biomass displayed separately for every gear and net.

3.5 Elemental Composition

Carbon contents for *E. hamata* ranged between 310.9 and 424.5 µgC/mg dry mass with a mean carbon content of 377.2 µgC/mg. This resulted in a total carbon content of 123.62 µgC/m^3 for station 19, 138.22 µgC/m^3 for station 27 and 136.96 µgC/m^3 for station 38. Carbon contents for *P. maxima* ranged between 201.5 and 322.0 µgC/mg dry mass with a mean carbon content of 298.9 µgC/mg. Linear relationships between body length and carbon content were found for neither of the two species.

C:N ratios for *E. hamata* ranged between 3.9 and 5.7 with a mean C:N ratio of 4.7. *P. maxima* had C:N ratios between 3.3 and 3.9 with a mean C:N ratio of 3.8.

3.6 Chlorophyll *a*

Concentrations of Chl*a* measured for the upper 100m of the water column are visualised in Figure 20. Station 19 had the highest concentration, with over 10 µg/L at 5 m depth. Stations 27 and 36 had lower concentrations in the vertical Chl*a* profiles (<4 µg/L) as well as in integrated Chl*a* concentrations for the 0-50 depth layer. Integrated Chl*a*-values for the stations were: station 19 - 287.35 mg/m^2, station 27 - 119.44 mg/m^2 and station 36 (as nearest station to station 38) - 112.22 mg/m^2

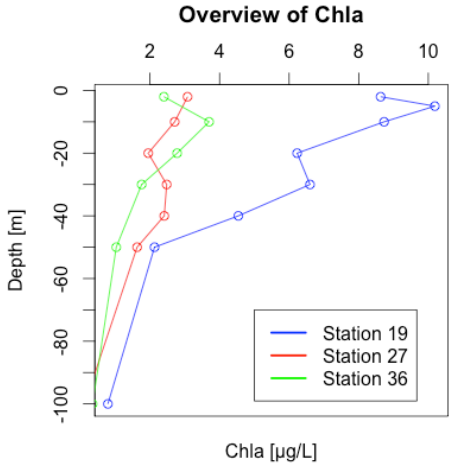


Figure 20 – Overview of Chl*a*: Vertical Chl*a* profiles for CTD stations near the SUIT and M-RMT stations. Data kindly provide by Dr. Ilka Peeken.

3.7 Temperature

Vertical temperature profiles near the investigated stations are depicted in Figure 21. Temperature ranged between -1.4 and -1.8 °C in the upper 30 m and reached up to 2.3–2.8 °C at 160-190 m depth. The thermocline at ~250 m for station 36 was located deeper than for the other two stations. The temperatures along the vertical profile were lowest for station 19.

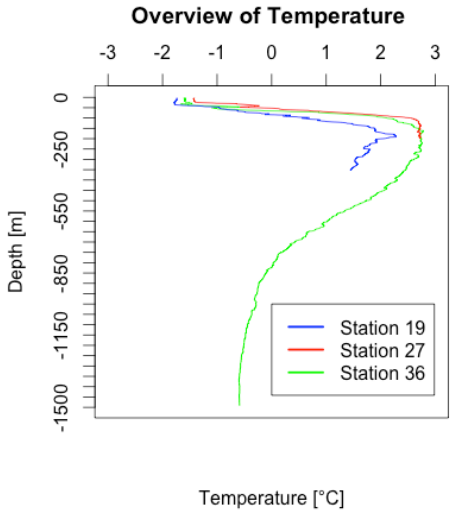


Figure 21 – Overview of Temperature: Vertical temperature profiles from CTD measurements near the SUIT and M-RMT stations investigated in the present study. Data kindly provide by Dr. Ilka Peeken.

4 Discussion

The current study aims at closing a gap in the understanding of the importance of chaetognaths in the Arctic Ocean.

4.1 Abundance and Distribution

Three species, *E. hamata*, *P. elegans* and *P. maxima*, were found in the present study. This meets expectations since they are the most common species in the study area and contribute substantially to zooplankton biomass in the Arctic Ocean (Søreide et al. 2003; Hopcroft et al. 2004).

E. hamata was the most abundant chaetognath at most stations under the ice and throughout the water column at stations towards the deep-sea basin. *P. elegans* was found in highest concentrations on the shelf whereas *P. maxima* was only found at stations on the slope. The results confirm the dominant role of *P. elegans* on Arctic shelves (Welch et al. 1996; Grigor et al. 2014b), while being a neritic expatriate in the Arctic basins (Kosobokova et al. 2010). The other two species are more abundant offshore (Kosobokova et al. 2010).

Samples of this study were collected in Arctic spring when zooplankton abundances are generally lower than after the spring bloom {Grigor:2014kk, (Herman 1989). In general the abundances were higher under the sea-ice than in the water column. Overall chaetognath abundance decreased when descending into deeper water layers. Nevertheless chaetognath abundances accumulated over the entire water column were higher in the deep basin than on the shelf. In the Antarctic chaetognath abundances were lower under the sea-ice than in the water column. Higher chaetognath abundances were observed at stations with higher densities of copepods and krill larvae (David 2015). (David 2015) assumes that copepods were attracted to under-ice resources during winter and chaetognaths in turn followed the copepods. Since the abundances of present study were surveyed in Arctic spring, this might also be the reason for the high abundances under the sea-ice. The sample from SUIT station 19-1 had very low overall biomass.

Overall chaetognath abundances found in the present study are in agreement with results for the central Nansen Basin in late summer with overall mesozooplankton abundance decreasing in deeper water layers (Auel and Hagen 2002). In the 0-50 m

layer 0.635 ind./m^3 were found in the Nansen Basin, compared to a mean of 0.695 ind./m^3 in the present study. In the 200-500 m 0.244 ind./m^3 were found in the Nansen Basin, compared to a mean of 0.081 ind./m^3 in the present study. It differed though for the 50-200 m depth layer, where (Auel and Hagen 2002) reported 1.591 ind./m^3 compared to 0.149 ind./m^3. Differences could arise through the different seasons in which studies were conducted.

4.1.1 P. elegans

P. elegans was most abundant on the Barents shelf, where it had higher abundances than *E. hamata*. *P. elegans* contributed to less than 7% of the chaetognath population under-ice and in the water column on the slope. *P. elegans* was only found above 200 m, with highest abundances between 0-50 m. This is in agreement with findings for Baffin Bay, Resolute and Svalbard of (Sameoto 1987), (Welch et al. 1996; Grigor et al. 2014b) and strengthens the hypothesis, that *P. elegans* is restricted to Arctic Ocean water (0-200 m). The abundances found in the present study resemble the proximity of the study area to the shelf since higher abundances have been reported in a near Svalbard (Grigor et al. 2014b), and lower abundances were estimated for the central Nansen Basin (David et al. 2015).

The abundance of 0.3 ind./m^3 in the upper 100 m on the shelf is comparable with abundances found in the Arctic Canada Basin where 0.14 individuals per m^3 were reported at a sampling depth of 100 m (Hopcroft et al. 2004). In comparison to the abundance in the upper 100 m at station 19 of this study of 9.1 ind./m^2, in the Barents Sea abundances for *P. elegans* were reported with 3.3 ind./m^2 in the upper 200 m (Søreide et al. 2003). In contrast, the encountered abundance of *P. elegans* is much lower than that in a fjord of Svalbard with 108 individuals per m^2 for this season (Grigor et al. 2014b). Nevertheless the abundance of *P. elegans* under the ice (<0.13 ind./m^3) is higher than that in the central Nansen and Amundsen Basin (0.0015 ind. /m^2) (David et al. 2015).

4.1.2 P. maxima

In total only two *P. maxima* were found resulting in very low abundances (<0.006 ind./m^3). *P. maxima* is generally found in meso- to bathypelagic depths in the central Arctic basins (Kosobokova et al. 2010), Though samples of the courser M-RMT nets contained very large chaetognaths (pers. observation), which may be *P. maxima*. Furthermore *P. maxima* specimens up to 60 mm of length, were identified in the

frozen samples used for biomass analysis taken from the courser M-RMT nets. Large chaetognaths could be avoiding the smaller net openings of the finer nets (Fleminger and Clutter 1965). Calculated abundances for *P. maxima* may therefor be misleading. This would also explain the discrepancy to other studies in the Arctic. Between the Canada Basin and Chukchi Sea (75° 21' – 75° 42' N) *P. maxima* was found throughout the water column (Dawson 1967). In Baffin Bay *P. maxima* was most abundant between 150 and 350 m at the transition zone between Arctic Ocean water and Labrador Sea water. Abundances reached up to 0.5 ind./m^3 in this area (Sameoto 1987).

4.1.3 Juveniles

Juveniles were most abundant on the shelf (0.6 ind./m^3). Adding up unidentified juveniles with stage 0 *Eukrohnia hamata* leads to 0.7 ind/m^3 on the shelf and 0.4 ind./m^3 in the basin. The abundance of unidentified juveniles was very high between 0 and 50 m and lower between 50 and 200 m. High densities of juveniles are typical for May and July. It is assumed that they are linked to the restocking of copepod nauplii following the phytoplankton boom in spring. Though as factors such as continuous light in the upper layer or the lower salinity due to fresh water runoff from the ice could also have an impact (Dawson 1967). The differences in mean lengths for unidentified juveniles in these two layers could indicate two different species. This hypothesis is strengthened when taking into account that *E. hamata* juveniles were numerous in the latter layer. At Weather Station P in the pacific, juveniles showed different but overlapping vertical distributions. Juveniles of *P. elegans* (stage 0) were found only above 25 m and juveniles and stages I *E. hamata* only deeper than 25 m (Sullivan 1977).

Juveniles were found under the ice only at one station. Only at station 38 were juveniles found below 200 m. This could be due to the vertical temperature profile at this station. The thermocline was located at approximately 300 m depth, forming a wider mixed layer above.

4.1.4 E. hamata

The abundances (0.3-0.8 ind./m^3) for *E. hamata* in the upper water column are a little lower than the abundances found in the Arctic Canada Basin (1.34 ind./m^3) (Hopcroft et al. 2004) in summer. In contrast in Baffin Bay abundances of *E. hamata* reached over 5 ind./m^3 (Sameoto 1987). In the Barents Sea (Søreide et al. 2003) encountered

2.9 ind./m^2. Abundances under the ice (<2.5 ind./m^2) were higher than those found in the Eurasian basin (0.11 ind/m^2) (David et al. 2015).

4.2 Distribution of Maturity Stages *E. hamata*

Seminal vesicles were hard to identify for *E. hamata*. Incipient seminal vesicles may have been missed. To reduce uncertainties sperm load in the tail segment was used as a characteristic to distinguish stage I from stage II adults. Furthermore broken seminal vesicles were possibly mistaken for incipient seminal vesicles. As sperm may only be partially discharged in stage III *E. hamata*, specimens with ova >0.04 mm were classified as stage III adults. Most chaetognaths <8 mm were not determined to species level. For a more precise estimate of stage distribution and life cycle analyses, all juveniles should be identified to at least genus level.

Stage 0 *E. hamata* were most abundant between 50 and 200 m. Stage I *E. hamata* were most abundant under the ice and between 0 and 50 m. Though many individuals were not classified for the layers below 50 m, percentages of *E. hamata* stages per layer and length histograms suggest stage I adults being present. They seem to be less numerous in layers below 50 m, especially at layers deeper than 200 m. Stage II *E. hamata* were most abundant under the ice and above 50 m. Length histograms indicate that they are also numerous between 200 and 500 m. One specimen for stage III was found below 200 m at station 38.

The results correspond to previously observed vertical distribution patterns of maturity stage with immature individuals populating the upper layers and mature specimen migrating to deeper layers for spawning (Dawson 1967; Timofeev 1998). This vertical distribution is typical for *E. hamata* in Arctic and Antarctic Oceans (Hagen 1999). (Timofeev 1998) suggests maturation and reproduction of Arctic *E. hamata* to take place in the Atlantic waters with temperatures near 0°C and salinities of 34.8-34.9%) .

The distribution of stage 0 is similar to the findings at Weather Station P where specimens of this species and stage were found only lower than 25 m (Sullivan 1977). The vertical distribution of stage 0 and I is in agreement with populations in Baffin Bay (Sameoto 1987) and Franz-Joseph Island (Dawson 1967) where juveniles and stage I *E. hamata* were concentrated in the upper 100 m. In contrast stage II individuals were most abundant between 200 and 500 m in Baffin Bay, whereas their abundance peaks under the ice and above 50 m for the present study in the Sophia Basin. The difference in distribution patterns for stage II could for one be due to the

more southern position of Baffin Bay (75 °N). Another reason could be the use of different stage classifications. Whereas (Sameoto 1987) used a more general classification (Sameoto 1973), the *E. hamata* of the present study were classified according to the stages introduced by (Alvariño 1990a).

In Baffin Bay stage III individuals were concentrated between 400 and 800 m depth (Sameoto 1973). In the Canada Basin and Chukchi Sea they were found below 500 m (Dawson 1967). The maximum sampling depth of the present study is 500 m at station 38. Stage III individuals were possibly below these layers. Specimens of stage IV were not found. This strengthens previous observations, that mature *E. hamata* descend to deeper layers for spawning. Individuals carrying brood pouches have been observed deeper than 700 m (Timofeev 1998). Mature individuals and are only known to ascend to layers above 500 m in September (Dawson 1967).

4.3 Biomass

Biomass found for *E. hamata* increased from the shelf toward the basin. Estimated values (0.328-0.366 mg/m^3) are lower than in other studies. Biomass for *E. hamata* in the Arctic Canada Basin reached 0.969 mg/m^3 (Hopcroft et al. 2004) and up to 0.02 g/m^3 in Baffin Bay (Sameoto 1987). (Sameoto 1987) observed a decrease in biomass south to north. Therefor biomass in the present study is expected to be lower than that of more southern regions. Highest densities of adult copepods were observed 3 weeks after the spring bloom, followed by a maximum abundance of *P. elegans* after 3 more weeks in Conception Bay (Choe et al. 2003). The Chl*a* values at the present stations indicate, that sampling was performed before or during spring bloom (Herman 1989), which could explain lower biomass.

4.4 C:N Ratios

The C:N ratio of *E. hamata* (mean 4.7) were considerably higher than those for *P. maxima* (mean 3.7). C:N ratios of *E. hamata* correspond to values found in previous studies for polar chaetognaths.

High C:N ratios are explained by oil droplets found in the intestine tissue of chaetognaths. The function of these oil droplets yet remains unclear, though they are assumed to act as buoyancy aid or energy deposit (Kruse et al. 2010b), {Oresland:1990wo}, (Terazaki 1993). In the present study oil droplets for *E. hamata* were observed which leaked from most specimens. The biochemical composition of *E. hamata* is not correlated with its reproductive cycle since high lipid values have

also been reported for immature specimens. Food availability could be a major factor {Bamstedt:1977ub}. This is also assumed for the present study, since C:N measurements were not related to body size of specimens, which increases with maturity. For Antarctic *E. hamata* C:N ratios varied between 4.3 in summer and 5.1 in winter by (Kruse et al. 2010b). She assumes better feeding conditions for chaetognaths in winter due to overwintering of some copepod species (Hagen 1999; Kruse et al. 2010b). Since C:N ratios of the present study reached over 5.1, the biochemical composition of *E. hamata* is similar to the Antarctic winter population.

There seems to be little knowledge about the C:N ratios for *P. maxima,* since published results could not be found. C:N ratios of *P. maxima* are in the range of values published for *P. elegans*. (Terazaki 1993) reported C:N ratios for *P. elegans* of 4.7 in the Japan Sea and 3.5 in the Pacific. In Conception Bay C:N ratios of 4.4 were found for *P. elegans* (Choe et al. 2003). (Choe et al. 2003) assumes that C:N ratios as well as lipid and carbohydrate levels for *P. elegans* are positively correlated to the maturity stage of chaetognaths as well as food quality.

4.5 Conclusions

P. elegans was mainly found on the shelf, whereas *E. hamata* was the dominant chaetognath species offshore. Juvenile chaetognaths were encountered in high abundances in the upper 200 m of the water column. Overall abundances of chaetognaths decreased in deeper water layers. Abundances under the sea-ice were higher than in the water column. Significant differences in overall abundances and biomass could not be found between the shelf station and stations towards the deep basin. High abundances of chaetognaths found under the sea-ice confirm the importance of the under-ice habitat in the Arctic Ocean (David et al. 2015). Since the Arctic sea ice extent is decreasing rapidly {Polyakov:2005ic}, an important habitat for chaetognaths may be at risk.

5 Literature

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6 Appendix

Table 7A – Abundances for examined stations of the present thesis. Listed are abundances for species, juvenile chaetognaths not identified to species level, as well as unidentified adult chaetognaths.

Gear	Station	Net	Depth Strata [m]	Bottom Detph [m]	Longitude (° E)	Latitude (° N)	Station Date	Abundance E. hamata	Abundance P. elegans	Abundance Juveniles	Abundance P. maxima	Abundance Unident. Chaetognaths
SUIT	19-1	PLK_2012	0-2	188.5	19.907	81.007	27.05.15	0.006	0	0	0	0
MRMT	19-2	1_1	50-100	168.1	19.715	81.04	27.05.15	0.158	0.061	0	0	0
MRMT	19-2	1_2	25-50	168.1	19.715	81.04	27.05.15	0.099	0.209	0.357	0	0
MRMT	19-2	1_3	0-25	168.1	19.715	81.04	27.05.15	0.043	0.057	0.201	0	0
SUIT	27-1	PLK_2012	0-2	824	17.753	81.372	31.05.15	0.799	0	0	0	0
MRMT	27-17	1_1	200-300	866.8	17.102	81.295	01.06.15	0.037	0	0	0	0.011
MRMT	27-17	1_2	50-200	866.8	17.102	81.295	01.06.15	0.062	0	0.006	0.003	0.022
MRMT	27-17	1_3	0-50	866.8	17.102	81.295	01.06.15	0.217	0	0.054	0	0.036
SUIT	38-1	PLK_2012	0-2	2250.1	16.31	81.32	09.06.15	1.186	0.062	0.062	0	0.250
MRMT	38-2	1_1	200-500	2255.7	16.112	81.337	09.06.15	0.092	0	0.017	0.006	0
MRMT	38-2	1_2	50-200	2255.7	16.112	81.337	09.06.15	0.108	0	0.026	0	0
MRMT	38-2	1_3	0-50	2255.7	16.112	81.337	09.06.15	0.677	0.027	0.108	0	0

Table 8A - List of chaetognaths used for analysis of elemental composition and biomass calculation.

Gear	Station	Depth Strata [m]	Net	Bottom Depth [m]	Longitude (° E)	Latitude (° N)	Station Date	Species	Dry Mass [mg]	Total Length [mm]	C:N Ratio
MRMT	28-5	100-200	8_1	904.5	19.30	81.50	02.06.15	P. maxima	23.6667	56.3	3.25
MRMT	27-17	50-200	8_2	866.8	17.10	81.30	01.06.15	E. hamata	4.7333	24.4	4.37
MRMT	27-17	50-200	8_2	866.8	17.10	81.30	01.06.15	E. hamata	8.7667	30.8	5.16
MRMT	27-17	50-200	8_2	866.8	17.10	81.30	01.06.15	E. hamata	5.8	26.1	5.27
MRMT	27-17	50-200	8_2	866.8	17.10	81.30	01.06.15	E. hamata	2.8333	22.0	
MRMT	27-17	50-200	8_2	866.8	17.10	81.30	01.06.15	E. hamata	4.6667		
MRMT	27-17	50-200	8_2	866.8	17.10	81.30	01.06.15	P. maxima	44.3667	58.0	3.88
MRMT	32-11	50-200	8_2	344.8	19.73	81.17	07.06.15	E. hamata	7.0333	28.1	4.83
MRMT	32-11	50-200	8_2	344.8	19.73	81.17	07.06.15	E. hamata	8.8	30.5	4.84
MRMT	32-11	50-200	8_2	344.8	19.73	81.17	07.06.15	E. hamata	8	30.2	4.88
MRMT	32-11	50-200	8_2	344.8	19.73	81.17	07.06.15	E. hamata	3.7667	22.3	
MRMT	32-11	50-200	8_2	344.8	19.73	81.17	07.06.15	E. hamata	2.5	20.1	
SUIT	32-12	0-2	SUIT_2012	345.7	19.71	81.18	07.06.15	E. hamata	7.4667	28.7	4.57
SUIT	32-12	0-2	SUIT_2012	345.7	19.71	81.18	07.06.15	E. hamata	7.5667	31.9	4.58
SUIT	32-12	0-2	SUIT_2012	345.7	19.71	81.18	07.06.15	E. hamata	6.5	27.9	5.07
SUIT	32-12	0-2	SUIT_201	345.7	19.71	81.18	07.06.15	E.	4.1667	26.5	

			2					hamata			
SUIT	32-12	0-2	SUIT_2012	345.7	19.71	81.18	07.06.15	E. hamata	5.8333	28.0	
SUIT	38-1	0-2	SUIT_2012	2250.1	16.31	81.32	09.06.15	E. hamata	4.5667	29.3	3.92
SUIT	38-1	0-2	SUIT_2012	2250.1	16.31	81.32	09.06.15	E. hamata	4.7	28.9	4.75
SUIT	38-1	0-2	SUIT_2012	2250.1	16.31	81.32	09.06.15	E. hamata	5.4	26.1	5.72
MRMT	38-2	200-500	8_1	2255.7	16.11	81.34	09.06.15	E. hamata	4.3667	22.5	4.23
MRMT	38-2	200-500	8_1	2255.7	16.11	81.34	09.06.15	E. hamata	5.0667	26.8	4.57
MRMT	38-2	200-500	8_1	2255.7	16.11	81.34	09.06.15	E. hamata	6.2	29.3	5.21
MRMT	38-2	200-500	8_1	2255.7	16.11	81.34	09.06.15	E. hamata	3.3667	21.5	
MRMT	38-2	200-500	8_1	2255.7	16.11	81.34	09.06.15	E. hamata	3.5333	24.5	
MRMT	38-2	200-500	8_1	2255.7	16.11	81.34	09.06.15	P. maxima	18.9667	48.8	3.54
MRMT	38-2	200-500	8_1	2255.7	16.11	81.34	09.06.15	P. maxima	46.9667	56.9	3.89
MRMT	38-2	200-500	8_1	2255.7	16.11	81.34	09.06.15	P. maxima	20.7667	49.6	4.25
SUIT	44-1	0-2	SUIT_2012	812	9.26	81.94	17.06.15	E. hamata	5.5333	27.8	3.88
SUIT	44-1	0-2	SUIT_2012	812	9.26	81.94	17.06.15	E. hamata	6.8	30.4	4.28
SUIT	44-1	0-2	SUIT_2012	812	9.26	81.94	17.06.15	E. hamata	4.5333	27.9	4.65
SUIT	44-1	0-2	SUIT_2012	812	9.26	81.94	17.06.15	E. hamata	2.5	23.7	
SUIT	44-1	0-2	SUIT_2012	812	9.26	81.94	17.06.15	E. hamata	2.9667	23.0	

MRMT	47-2	200-300	8_1	2145.4	13.61	81.36	19.06.15	P. maxima	10.1333	35.6	3.63
MRMT	47-2	200-300	8_1	2145.4	13.61	81.36	19.06.15	P. maxima	29.6667		3.83
MRMT	47-2	200-300	8_1	2145.4	13.61	81.36	19.06.15	P. maxima	37.4333	59.5	3.95
	47-23	200-1000	8_1	2175.4	13.61	81.33	21.06.15	P. maxima	56.8667	66.9	3.71
	47-23	200-1000	8_1	2175.4	13.61	81.33	21.06.15	P. maxima	45.5333	63.9	4.00

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Eigenständigkeitserklärung

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