

The effect of predatory chaetognaths on zooplankton assemblages at the start of the spring bloom in Glacier Bay, Alaska, U.S.A.

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Abstract

Chaetognaths are highly prolific marine worms that are second only to copepod crustaceans in terms of abundance and biomass in the world's oceans. While juvenile chaetognaths feed on small prey like tintinnids and rotifers, the main diet of adult chaetognaths consists of copepods and other crustacean nauplii. It is thought that chaetognaths have the potential to affect, and possibly structure, their prey communities. Chaetognath and zooplankton abundances were measured in Glacier Bay, Alaska during 19-22 March 2008. It is hypothesized that higher chaetognath abundances will have a negative impact on prey abundance. Vertical net tows were performed at 9 stations throughout Glacier Bay. The overall zooplankton abundance was low (average 291 individuals m^{-3}) and chaetognaths were found throughout the main basin (average 0.3 ind. m^{-3}) and the western arm (average 0.5 ind. m^{-3}). Elevated juvenile chaetognaths occurred predominantly in the northern main basin where adult abundances were very low. Abundant juvenile prey, though not quantitative, were found throughout the bay. Adult chaetognaths were found to have a significant negative effect on their total prey abundance. This same correlation was found

in regards to *Calanus* copepods suggesting that copepods are likely the preferred prey of adult chaetognaths. An insignificant correlation was found between adult chaetognaths and non-copepod crustaceans, suggesting they are used as a supplemental prey.

Introduction

Commonly called arrow worms, chaetognaths are transparent torpedo shaped marine organisms that range in size from 2 mm to 12 cm. They are highly prolific animals that are second to copepod crustaceans in terms of abundance and biomass in the world's oceans (5 to 15% biomass through world's oceans; Longhurst 1985, Vannier 2007). Chaetognaths are important zooplankton predators in the sea (Reeve 1980, Feigenbaum 1984). Most are ambush feeders that detect their prey by sensing hydrodynamic signals using mechanoreceptors (Feigenbaum 1984, Tonnesson 2005) and capturing with chitinous grasping spines on both sides of their head (Fulmer 2005). The sensitivity of these mechanoreceptors sets the limit of the smallest prey item the chaetognath can catch and the largest size limit is set by the size of the chaetognath's mouth opening (Pearre 1980, Sullivan 1980).

While young chaetognaths may value small prey such as tintinnids and rotifers, the main

diet of adults consist of copepods and other crustacean nauplii (Pearse 1987, Feigenbaum 1991, Duro 2000). This creates an extremely important link in energy transfer between copepods and higher trophic levels (Terazaki 1998, Fulmer 2005). Barnacle nauplii, appendicularians, cladocerans, and fish larvae also contribute to the chaetognath diet periodically (Rakusa-Suszczewski 1967, Pearre 1974, Oresland 1987). Chaetognaths show a selective nature to their feeding habits which may be based on size, shape, movement pattern, or the escape capability of the prey item (Feigenbaum 1991, Alvarez-Cadena 1993, Saito 2001).

Chaetognaths have the ability of producing one to five or more generations during one year (Terazaki 1998, Fulmer 2005) depending on temperature. Population dynamics and distribution of chaetognaths are reported to be determined by prey availability but this relationship is unclear (Fulmer 2005). Arctic chaetognaths are thought to represent a significant portion of biomass due to their long life cycle of approximately two years and are important in controlling *Calanus* copepod populations (Hopcroft 2005). Due to their ability to reproduce quickly and long life cycle, chaetognaths have the potential to affect, and possibly structure, their prey communities (Alldredge 1984, Terazaki 1995).

Despite chaetognaths' importance to their habitat, aspects of their distribution and biology are not as well known in comparison to other crustaceans (Brodeur 1999). Most studies that have examined chaetognath distribution and diet in the north-east Pacific Ocean have been in open ocean populations (Kotori 1976, Sullivan 1980, Terazaki 1986). Work with coastal populations (Lea 1955, Gardner 1982, Mackas 1992) was to British Columbia until Brodeur and Terazaki (1999) studied the northern Gulf of Alaska to determine chaetognaths importance on the microzooplankton community as a whole.

Because chaetognaths are important predators of zooplankton and compete with larval fish for prey, it is suggested they could have a

significant effect on the zooplankton assemblage in a highly productive area such as Glacier Bay, Alaska. Glacier Bay is a fjord in southeastern Alaska that extends northward and bifurcates into the western arm and Muir Inlet (Fig. 1). This system is of particular interest due to its rapid deglaciation and the resulting changes on this estuarine environment (Etherington et al 2004). The lack of published literature on chaetognaths in Glacier Bay does not reflect their trophic significance in this system. In this study, the abundances of zooplankton and individual size fractionations were measured to determine chaetognaths food availability and predation impact. It is hypothesized that areas with higher abundances of chaetognaths will have a decreased abundance of prey items, namely copepods and crustacean nauplii.

Methods

Abundance and composition of zooplankton communities were measured at stations outside Glacier Bay and south of Sitakaday Narrows, through the main basin and western arm, ending close to the glacier in northern Tarr Inlet. Stations 1, 4, 5, 8, 10, 11, and 21 correspond to the oceanographic stations of the United States Geologic Service as well as the National Park Service (Etherington 2004) while stations AA and 000 (Table 1) were created for the purpose of this cruise. Most samples were depth integrated by using a vertical plankton net tow (Table 1).

A total of nine stations were sampled (Fig. 1) throughout Glacier Bay on 19-22 March 2008 aboard the *R/V Thomas G. Thompson*. At stations 4, 5, 8, 10, and 21, a vertical net tow was cast with a 0.5-m 64-micron mesh, while a 1-meter 216-micron mesh plankton net was used at stations 10 and 11, from 75m to the surface, with the exception of station 4 which went to 50m (Table 1). Nets were raised at varied rates $<0.5 \text{ m s}^{-1}$ to prevent damage to delicate organisms (Table 1). At stations 000,

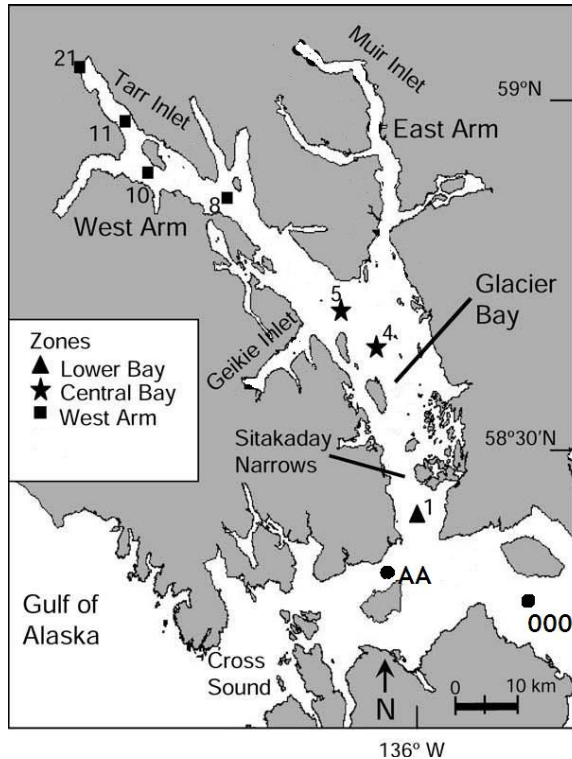


Figure 1: Map of the 9 stations in Glacier Bay, Alaska that were sampled in 19-22 March 2008 (modified from Etherington 2007).

1, 5, and 11, horizontal tows were used in an effort to collect gelatinous zooplankton samples other than chaetognaths. These tows were performed by rigging vertical nets into Bongo nets and towing them horizontally through the water by moving from 5m for 2 min to the surface for 2 min and back to 5 m continuing the cycle for 10 min while the ship moved at a constant 0.5 knots. Variations in nets and ascension rates occurred while looking for other types of gelatinous zooplankton. Once on deck, organisms in the net were carefully removed by rinsing with sea water towards the cod end. In the shipboard lab, samples were concentrated by straining them through a 333-micron cod end. Samples were placed into labeled jars and 40 ml of a 10% un-buffered formalin solution was added to preserve the sample for transfer back to the University of Washington for lab analysis.

In the lab, sufficient Rose Bengal powder was

added to stain the sample and organisms light pink for easier identification. The zooplankton samples were split into statistically representative sub-samples using a plankton splitter. The contents of the sample were strained through a 100-micron mesh and transferred into fresh water (approx 50mL) to allow better performance of the plankton splitter and reduce exposure to formalin during the counting process. Small amounts of the sub-sample were placed into a Petri dish then put under a dissecting scope with a measurement ocular to be identified using field guides (Smith 1996), counted, and measured for length. Upon completion of the sub-sample, the remainder of the sample was examined under the dissecting scope to look for organisms not in the sub-sample and determine quantitative counts of large copepods and adult and juvenile chaetognaths. Juvenile chaetognaths were classified as being less than 5 mm in size and adults being 5 mm or larger. Samples were then strained back into their station water with formalin. For this study, only samples 4, 5, 8, 10.1 (Station 10 Tow 1), 10.3, 11, and 21 were used to minimize variability due to method differences though all samples were saved for the archive that will be located at the University of Washington’s School of Oceanography in Seattle, Washington.

Results

Numbers of chaetognaths collected in Glacier Bay from 19-22 March 2008, were very low and ranged between 0 and 46 individuals (0.8 individuals m^{-3}) per station. Adult chaetognaths occurred dominantly at stations 4, 8, and 10 (Fig. 2). Juvenile chaetognath abundances ranged between 0 and 15 individuals (1.0 ind. m^{-3}) and were only dominant at station 5, while adults ranged from 0 to 45 individuals (0.8 ind. m^{-3}). The average abundances of adults and juvenile chaetognaths in Glacier Bay were estimated at 0.4 and 0.3 ind. m^{-3} respectively, disregarding stations 11 and 21 where no chaetognaths were

Station	Date	Time (PST)	Latitude (deg N)	Longitude (deg W)	Net Tow Hor/Ver	Net Type	Rate	Tow Depth
4	3/19	03:00	58 39.0790° N	136 06.773° W	Vertical	0.5m-64µm	0.5m s-1	50m
CS2/5	3/19	05:10	58 43.2064° N	136 15.0156° W	Vertical	0.5m-64µm	0.33m s-1	75m
11	3/19	16:50	58 58.0419° N	136 54.5177° W	Vertical	1m-216µm	0.33m/s	75m
11H	3/19	19:30	59 58.0419° N	137 15.0156° W	Horizontal	0.5m-64µm	0.5 Knot 10min	Surface
10 Tow 1	3/20	05:30	58 53.9659° N	136 50.2977° W	Vertical	1m-216µm	0.08m s-1	75m
10 Tow 2	3/20	05:50	58 53.9659° N	136 50.2977° W	Vertical	1m-216µm	0.08m s-1	75m
10 Tow 3	3/20	06:10	58 53.9659° N	136 50.2977° W	Vertical	0.5m-64µm	0.08m s-1	75m
10 Tow 4	3/20	06:30	58 53.9659° N	136 50.2977° W	Vertical	0.5m-64µm	0.08m s-1	75m
21	3/20	16:30	59 02.8387° N	137 03.3522° W	Vertical	0.5m-64µm	0.25m s-1	75m
8	3/21	03:30	58 51.9190° N	136 35.5158° W	Vertical	0.5m-64µm	0.08m s-1	75m
AA	3/21	08:30	58 17.7171° N	136 14.9251° W	Vertical	0.5m-64µm	0.08m s-1	75m
5	3/22	01:00	58 42.2817° N	136 13.8580° W	Horizontal	1m-216µm	0.5 Knot 10min	Surface
1	3/22	16:00	58 24.77° N	135 59.57° W	Horizontal	1m-216µm	0.5 Knot 10min	Surface
000	3/22	19:46	58 12.6964° N	136 20.5378° W	Horizontal	1m-216µm	0.5 Knot 10min	Surface

Table 1: Sampling methods used in the 19-22 March 2008 study in Glacier Bay, Alaska

found. Large variability in the abundances of adult and juvenile chaetognath populations between stations coupled with low overall numbers made estimating chaetognath populations early in the season difficult.

Copepods constitute a major prey item for adult chaetognaths. Adult copepods were abundantly found in Glacier Bay (average of 553 individuals). Copepod abundance was assessed in two separate orders Calanoid and Cyclopid copepods. Calanoid copepods dominated the copepod community and occurred in two distinct size classes, a smaller size ranging between 0.1 to 1.3 mm and the larger in the size ranging between 1.6 to 2.6 mm (Fig. 3). These two size classes were consistent throughout the stations with an average abundance of 34 ind. m⁻³ for the larger size class and 123 ind. m⁻³ for the smaller Calanus copepods.

Collectively crustaceans other than copepods were the second most abundant component of

the community, constituting 18% of the crustacean abundances, which included barnacle nauplii, crab zoea, amphipods, shrimp, and unidentified crustacean nauplii. Barnacle nauplii were most abundant at stations 10, followed by 5, 11, and 4, and least abundant at stations 21 and 8, with an average abundance of 14 ind. m⁻³ across the stations. Barnacle nauplii were only a large component at station 11, measuring 42% of the total zooplankton community, while the remainder of the stations on average had 4% barnacle nauplii (Fig. 4). Crab zoeas were found exclusively at station 4 with an abundance of 1.6 ind. m⁻³. Amphipods were found at every station in low numbers except 11. Only station 4 had sufficient amphipod numbers for abundance estimates (10 ind. m⁻³). Other stations averaged 0.3 ind. m⁻³. Shrimp were found exclusively at stations 4 and 11 with an average abundance of 0.3 ind. m⁻³. Overall, shrimp abundances were only a small compo-

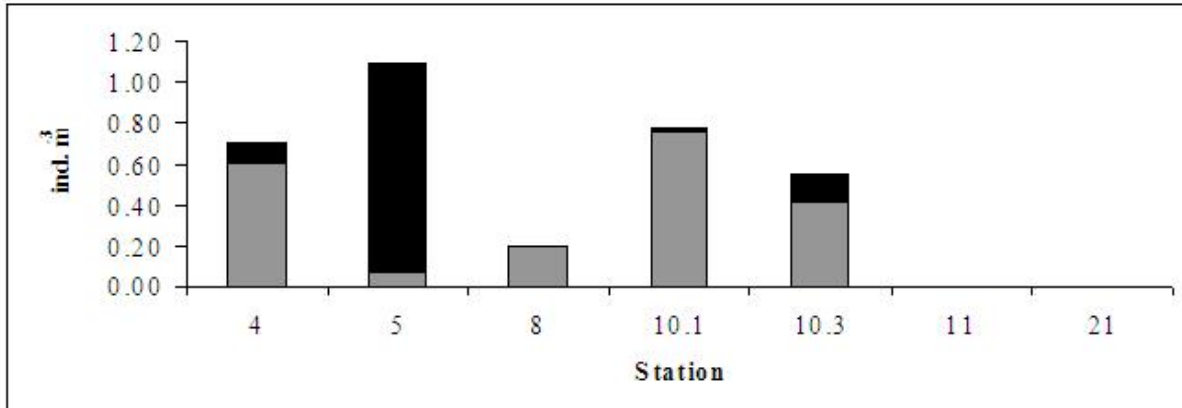


Figure 2: Abundances of juvenile (black) and adult (gray) chaetognaths found at each station.

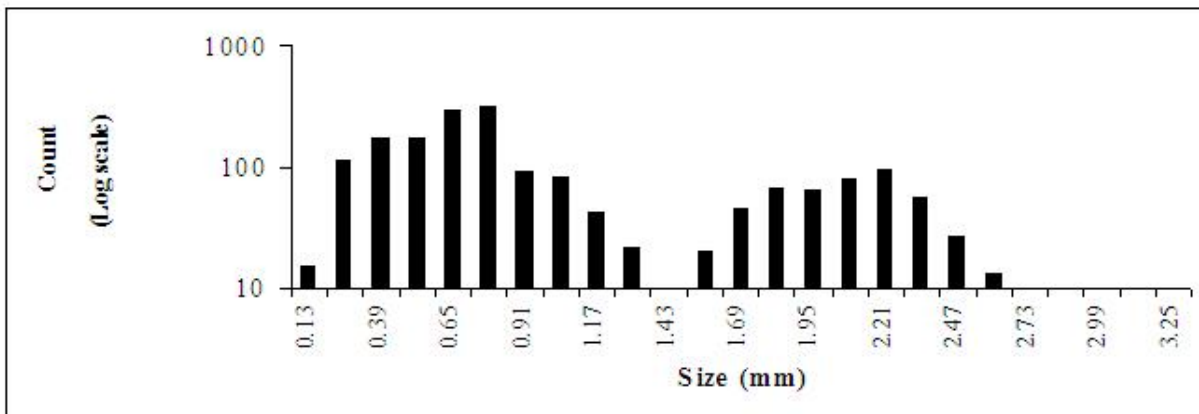


Figure 3: The size spectrum of *Calanus* copepod allowed the distinction of two separate size classes in Glacier Bay.

ment of the population and made up an average of 0.01% of the non-copepod crustacean population. The largest component (36%) of the non-copepod crustacean population was unidentified crustacean nauplii. There appeared to be three ‘species’ that comprised this population but full identification was not completed. Stations 4 and 5 had the highest abundance, with an average of 145 ind. m⁻³, while stations 8, 10, and 21 had an average abundance of 41 ind. m⁻³. Unidentified crustacean nauplii were not found at station 11, likely due to the use of the 216-micron mesh net. Sample 10.1, also utilizing the 216-micron mesh net, did not have nauplii despite their presence in 10.3, which utilized the 64-micron mesh net.

Although not a component of the chaetognaths’ diet, snail larvae were found consistently in the samples, with the exception of station 11, again likely due to the use of the 216-micron mesh net. The abundance of the larval snails varied, with station 4 and 5 being the highest (average of 52 ind. m⁻³), stations 8 and 10 with an average of 26 ind. m⁻³, and station 21 with an abundance of 6.5 ind. m⁻³. Another non-diet organism with an abundance greater than 1% of the total community was a larval bivalve found most abundantly at station 21 (19% of the total community (Fig. 4); 24 ind. m⁻³). Station 10 had an average between samples 10.1 and 10.3 of 1.7% of the total station community

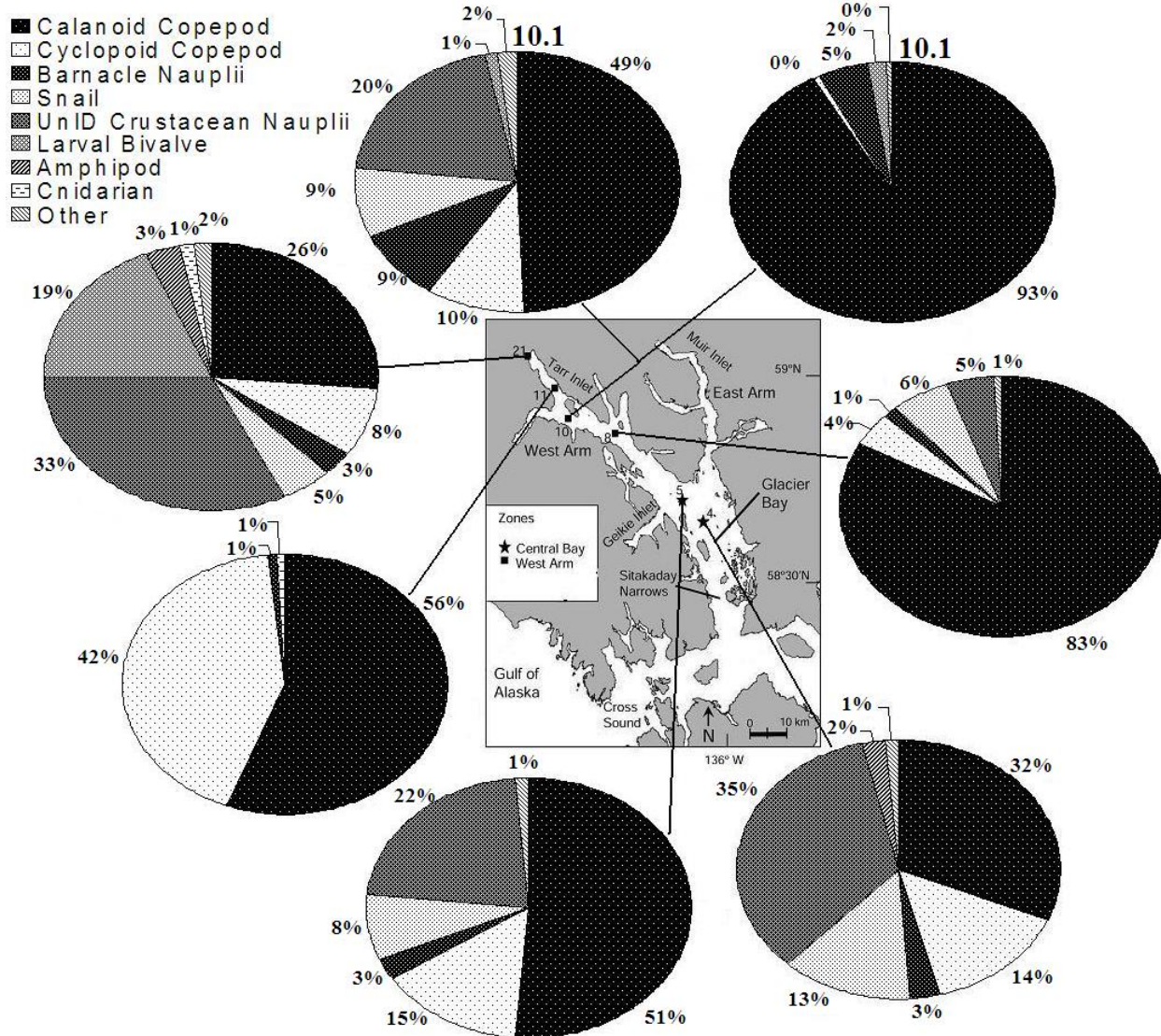


Figure 4: The compositions of Glacier Bay zooplankton community at each sample site.

and abundance of 4 ind. m⁻³ of larval bivalve.

Components of the population that comprised less than 1% of the total population were lumped into the category ‘other’ (Fig. 4). At station 4, this respective category was comprised of crab zoea, larval fish, worms, and shrimp. At station 5, the composition differed and included amphipods, larval jellies, and worms. Station 8’s others were amphipods, pteropods, larval jelly, and larval worm. Station 10’s sample 10.1 had larval fish and amphipods while sample 10.3 had the addition of cnidarian

and pteropod. Station 11 contained larval bivalves, pteropods, larval fish, and larval worms and station 21 had medusa jellies, cnidarians, and larval worms. Other organisms that were seen but not quantitatively assessed or identified were organisms that looked like eggs, rotifers, and small ellipsoid organisms with spines. Both eggs and rotifers were abundant throughout all the stations, though rotifers qualitatively appeared to be more numerous at station 21.

Discussion

The overall zooplankton abundance was low during March of 2008. Zooplankton abundance was highest (average of 526 ind. m^{-3}) in the main basin. As we moved into the western arm, zooplankton abundances decreased (average of 276 ind. m^{-3}) and reached a minimum in Tarr Inlet (average of 78 ind. m^{-3}). The overall low abundance during the month of March is consistent with the findings in the Gulf of Alaska and Prince William Sound, Alaska. Cooney et al (2001) found strong seasonal variability in the abundance of zooplankton in Prince William Sound with the end of winter (February and March) denoting the beginning of the season and peaking in June. Coyle and Pinchuk (2003) reported similar findings in the Gulf of Alaska during their 1997 to 2000 study with a mean abundance for March <50 ind. m^{-3} and a maximum in May. The low zooplankton abundances found in Glacier Bay, while consistent with the seasonal variations, is however larger than those found in the Gulf of Alaska (Prince William Sound is inconclusive due to the graph axis) corroborating Glacier Bay's overall high annual productivity.

Chaetognaths were found at all stations except 11 and 21. It is not clear if the lack of chaetognaths at these locations is due to spatial variations, temporal differences, or other environmental factors. The northern end of Tarr Inlet still had floating ice and cnidarians and medusa jellies present, with the latter two occupying the same ecological niche as chaetognaths. More likely, however, is that these two stations were sampled during the mid-day compared to the midnight and early morning hours of the other tows. It is widely recognized that chaetognaths vertically migrate to the surface at night, following the same migration of their primary prey, copepods (Tonnesson 2005). Although the samples were depth integrated to avoid this loss, a corresponding decrease in copepods (night stations average 250 ind. m^{-3} ; day samples average 32 ind. m^{-3}) further enhances migration

as the reason for the absence of chaetognaths.

There was a noticeable anomaly at station 5 where predominantly juvenile chaetognaths and a very low abundance of adults (Fig. 2) were encountered. This is a strong contrast to other stations where there were typically more adults with little to no juveniles. Because juveniles are highly susceptible to cannibalism (Tonnesson 2005), the low abundance of adults here is favorable to juvenile chaetognaths. Unfortunately, low abundances of chaetognaths in general made further examination of these trends inconclusive.

The food spectrum for juvenile chaetognaths is very different from that of adults (Tonnesson 2005). Juvenile chaetognaths mainly feed on tintinnids, a single-celled ciliate, and rotifers, a microscopic multi-cellular organism (Tonnesson 2005). Though not quantitative, rotifers were found throughout the Bay despite the presence of juveniles, with a seemingly increased abundance at station 21 which coincides with a lack of juvenile chaetognaths. Tintinnids were not seen due to optical limitations of the dissecting scope. It is speculated that further quantitative analysis of rotifers and tintinnids might explain observed patterns of juvenile chaetognath abundance, particularly the relatively high abundance of juveniles at station 5.

Adult chaetognaths selectively feed on crustaceans which was reflected in the abundance of the crustacean prey population. At station 4, there was an overall prey abundance of 393 ind. m^{-3} . This abundance peaked at station 5 (549 ind. m^{-3}), decreased at station 8 (412 ind. m^{-3}), and then sharply declined as we moved north into Tarr Inlet hitting a low at station 11 (34 ind. m^{-3}) (Fig. 5). A significant negative correlation was found with regards to the abundance of adult chaetognaths and the total abundance of prey (Spearman Rank correlation (two sided) $\rho=-0.9$, $n=5$, $p=0.07$) supporting the hypothesis that chaetognaths significantly impact the total crustacean population of Glacier Bay at the start of the spring bloom.

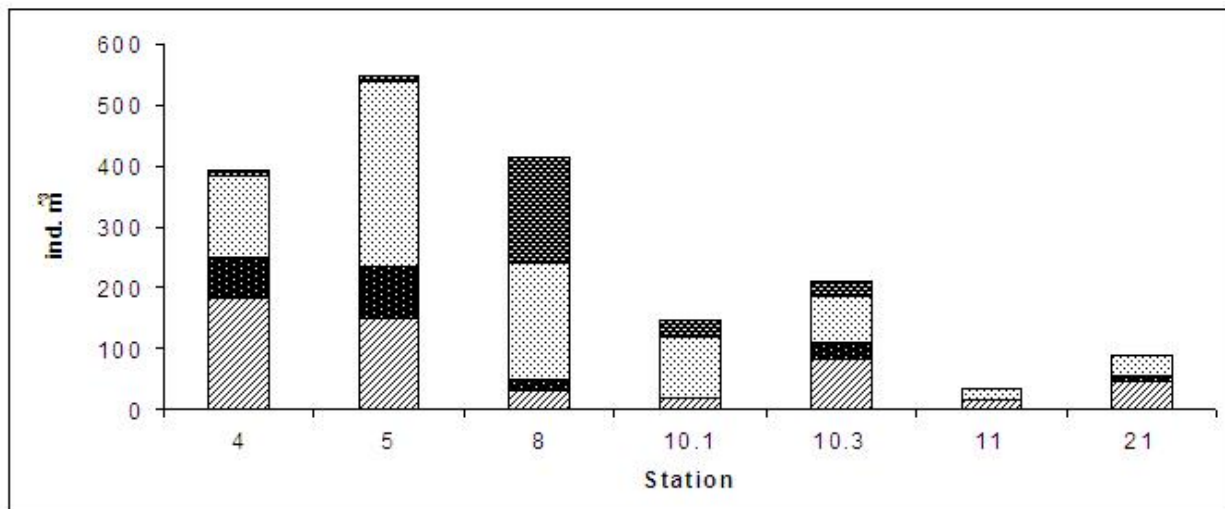


Figure 5: The total prey available to adult chaetognaths declines moving north through Glacier Bay. Abundances of non-copepod crustaceans, cyclopid copepods, small *Calanus* copepods, and large *Calanus* copepods.

Calanus copepods were the most commonly found prey item and, therefore, most likely preyed upon because of an expected high chaetognath-prey encounter probability. Stations 5 and 8, with a lower adult chaetognath abundance, had an average *Calanus* copepod abundance (338 ind. m^{-3}) 2.7 times larger than stations 4 and 10 (average of 123 ind. m^{-3}) (Fig. 5) with abundances of adult chaetognath being 4.4 times larger (Fig. 2). Again a significant negative correlation was found (Spearman rank correlation (two-sided) $\rho = -0.7$, $n = 5$, $p = 0.16$) between adult chaetognaths and *Calanus* copepods supporting the hypothesis that chaetognaths can significantly decrease the pre-bloom *Calanus* copepod population in Glacier Bay. This finding is in line with results from previous research. Kimmerer (1984) found chaetognaths removed 4 to 12% of the copepod standing stock each day. Sameoto (1973) estimated that *Sagitta elegans*, a north Pacific species of chaetognath, consumed up to 50% of the of the winter copepod production and Oresland (1990) estimated that chaetognaths could reduce copepod populations by up to 12% in the winter.

No significant correlation was found be-

tween adult chaetognaths and non-copepod crustaceans leading to the idea that they are likely to be secondarily preyed upon. They were not as abundant as *Calanus* copepods and are smaller in size, which equates to higher energy expenditure to hunt with a smaller caloric return. Due to this, it is likely these non-copepod crustaceans are used to supplement the diet of adult chaetognaths. This is supported by gut analysis performed by Tonnesson (2005) which showed high percentages of copepods with smaller contributions of nauplii as well as the insignificant correlation between adult chaetognaths and non-copepod crustaceans found here.

Glacier Bay, being a highly productive region, is well suited to support a high chaetognath abundance without food being a limiting factor. There is an abundance of prey even at the start of the spring bloom. Based on these observations, juvenile and adult chaetognaths populations are spatially separated. Station 5, centrally located in the upper main basin with easy access to both the eastern and western arms, appears to be a nursery ground for juvenile chaetognaths. There was an abundance of juvenile prey and safety from cannibalism, both

needed for juveniles to reach adulthood. High abundances of crustaceans are also available once they reach adulthood. From this very limited study, it appears the main basin is critical for successful chaetognath recruitment.

Conclusions

- The overall zooplankton abundance was low during the month of March in Glacier Bay which compares to the seasonal patterns of the Prince William Sound and the Gulf of Alaska.
- Chaetognaths were found throughout the main basin and the western arm. Juvenile chaetognaths were dominantly found at station 5 separate from the adults.
- Qualitative assessment of juvenile prey items, tintinnids and rotifers, suggests occurrence throughout the bay.
- Quantitative assessment of adult chaetognaths and their prey populations showed a statistical decline supporting the hypothesis presented here.
- This same correlation was found in regards to *Calanus* copepods which supports copepods being the main prey item of adult chaetognaths.
- The lack of correlation was found between adult chaetognaths and non-copepod crustaceans suggest they are used as a supplemental prey item.
- Overall, Glacier Bay is a suitable ecosystem for chaetognaths because food abundance is not limiting during pre-bloom conditions.

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