Accepted Manuscript

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PII: S0924-7963(17)30286-5
DOI: doi: 10.1016/j.jmarsys.2017.06.006
Reference: MARSYS 2994

To appear in: *Journal of Marine Systems*

Received date: 22 February 2016
Revised date: 14 June 2017
Accepted date: 28 June 2017

Please cite this article as: Siri Elise Enoksen, Henning Reiss , Diet of Norwegian coastal cod (Gadus morhua) studied by using citizen science, *Journal of Marine Systems* (2017), doi: 10.1016/j.jmarsys.2017.06.006

Diet of Norwegian coastal cod (*Gadus morhua*) studied by using citizen science

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Abstract

The Norwegian coastal cod (*Gadus morhua*) is a keystone species in the food web of northern Norwegian fjords. Their relatively stationary populations might specifically depend on local food resources, but the diet of cod has rarely been studied in fjord systems. Using a citizen science approach, where recreational anglers and tourists participated in the sampling, we studied small-scale differences in the diet composition of cod in a fjord system in northern Norway. We compared the cod diet from the MPA Saltstraumen, characterised by strong tidal currents and a highly diverse and abundant fauna, with the inner fjord area of Skjerstadfjord. The diet composition of cod significantly differed between both areas within the fjord. Although fish was the dominant prey in both areas, cod consumed more than 40% invertebrates in terms of weight, even in the cod size class of 70-99 cm. The invertebrate prey also caused the observed spatial differences. In Saltstraumen, brittle stars (Ophiuroidea), crabs (Brachyura) and sea cucumbers (Holothuroidea) were important food sources for cod, while sea urchins (Echinoidea), clams (Bivalvia), shrimps (Caridea) and krill (Euphausiacea) dominated the diet in the inner Skjerstadfjord. The high densities of sessile fauna in the dynamic environment of Saltstraumen, was only partly reflected in the diet of cod, with only Holothuroidea found in 17% of the stomachs. High rates of empty stomachs (24%), cannibalism as well as a higher proportion of low-energy prey in the diet of large cod, may indicate a shortage of high quality food in Skjerstadfjord. The samples for this study were collected through a citizen science campaign. This approach might provide opportunities to be used for coastal ecological monitoring with potential applications in local ecosystem management strategies through public involvement.

Keywords: food webs, sub-arctic fjords, benthos, stomach content, ecosystem management

1. Introduction

In sub-arctic and arctic waters of the Northeast Atlantic, populations of cod (*Gadus morhua* L. 1758) play an important role in marine food webs and are of high commercial value. Along the Norwegian coast, the exploitation of the two cod stocks, north-east arctic cod (NEAC) and Norwegian coastal cod (NCC), resulted in approximately 238 000 tonnes cod caught within the 12 nautical mile zone in 2014 (ICES, 2015). NEAC and NCC stocks are assessed separately, but they are managed as one unit (Reiss et al., 2009), although the two populations usually inhabit different regions along the coast. The NEAC migrates between their feeding grounds in the Barents Sea and the main spawning grounds along the north Norwegian coast, while the NCC permanently inhabits coastal areas and fjords, migrating only over short distances (Myksvoll et al., 2014). This has led to a debate about potential metapopulations of NCC in fjords, which are not necessarily genetically differentiated, but may show local population dynamics (Myksvoll et al., 2014; Smedbol and Wroblewski, 2002). Consequently, the NCC populations and the potential fjord sub-populations would be strongly dependent on the local environmental conditions and food resources. Thus, variability in food availability, and spatial or temporal changes in prey within fjords might specifically affect the NCC populations.

In general, the diet composition of Atlantic cod is relatively well studied. Juvenile cod (up to 25 cm length) feeds mainly on planktonic crustaceans (such as Euphausiacea and copepods) (Swalethorp et al., 2014), progressively replaced by benthic invertebrates such as shrimps and crabs (Arnott and Pihl, 2000; Bromley et al., 1997), while the diet of larger individuals is dominated by fish (Link and Garrison, 2002). However, the diet composition can vary substantially between regions, when comparing studies from e.g. the Barents Sea (Dolgov et al., 2008), Iceland (Jaworski and Ragnarsson, 2006), the Baltic Sea (Pachur and Horbowy, 2013), the Celtic Sea (Du Buit, 1995), the Norwegian Skagerrak coast (Hop et al., 1992) and Balsfjord in northern Norway (Klemetsen, 1982), and it often reflects the prey available in an ecosystem (Link et al., 2009; Svåsand et al., 2000). A comparison of cod diet along the Norwegian coast revealed that the diet changed in accordance to the distributions and abundances of prey species. In southern and western Norway, wrasses and gobies were important fish prey, whilst Euphausiacea, capelin and herring were of high importance in northern Norway (Svåsand et al., 2000). On local spatial scales, e.g. within a fjord, knowledge on diet composition is meagre.

Cod in northern fjords is a keystone species in the food web and can have large impacts on other trophic levels (Link et al., 2009; Pedersen et al., 2008). For the migratory NEAC in the Barents Sea, the diet significantly affect the cod population, if the main prey species, e.g. capelin, are strongly fluctuating (Link et al., 2009; Mehl, 1991), but also a relative robustness to prey fluctuations was reported, mainly because of the mobility and wide distribution of NEAC (Durant et al., 2014). This might not be the case for the relatively stationary cod in the fjords. Differences in the diet of cod within a fjord were found by Kanapathippillai et al. (1994), with the inner fjord characterised by an invertebrate dominated cod diet, whereas fish dominated their diet in the outer fjord. Thus, although cod is a mobile omnivore species, differences in cod diet on small spatial scales may be prevalent with potential ramifications for population dynamics and prey communities. Therefore, we investigated the diet of NCC in a north Norwegian fjord system with contrasting habitats aiming at a better understanding of the role of small-scale differences in food availability for the diet of cod.

Local residents and tourists commonly fish especially coastal cod along the Norwegian coast, and recreational fishing is an important part of the Norwegian tourist sector (Vølstad et al., 2011). An increasing effort in the recreational fishery at coastal stocks has imposed a greater awareness of the potential effects on the coastal fish stocks in Norway (Solstrand, 2013) and worldwide (e.g. Arlinghaus and Cooke, 2005). As a consequence, there is a growing need for new local management strategies that on the one hand sustain recreational fishing with its socio-cultural values and on the other hand protect vulnerable coastal fish stocks (Solstrand, 2013). Ideally, these strategies should aim for active participation of the local community and require alternative local monitoring tools to assess fjord stocks. Therefore, we used a citizen science approach to collect samples in this study. Citizen science has become an increasingly important tool in ecological research with its ability to engage large numbers of the public to collect data that could otherwise not be generated on the same spatial and temporal scales (e.g. Dickinson et al., 2012; Kobori et al., 2016). In our study, this approach was used to involve the local people and tourists in the research process and at the same time to raise the awareness for fjord ecosystems.

Thus, the main research objective of this study was to investigate the small-scale differences in diet composition of coastal cod within a fjord system, *i.e.* between an area with high invertebrate abundance and diversity and the inner fjord area. We hypothesised that high abundance of invertebrate prey significantly affects the diet composition of cod. Furthermore, we aimed at assessing the applicability of a citizen science approach for ecological studies in coastal systems.

2. Material and Methods

2.1. Study area

The two study areas, Saltstraumen and the inner part of Skjerstadfjord, are part of the fjord system Saltfjord – Skjerstadfjord, situated in northern Norway (Fig. 1). The fjords are connected through the narrow and shallow trench Saltstraumen with a sill depth of 26 m and a width of about 250 m (Eliassen et al., 2001). Saltstraumen is considered the worlds strongest tidal current that reaches an average velocity (at spring tide) of 6 m s^{-1}, but maximum velocity can even exceed 10 m s^{-1} at some locations (Gjevik, 2009). The Saltstraumen trench is inhabited by a highly diverse invertebrate fauna with particularly high densities of sessile filter feeders and hyperbenthic predators such as e.g. Actiniaria, Alcyonacea, Porifera and Holothuroidea (Fagerli et al., 2015). Also demersal fish species are highly abundant including Atlantic cod (*Gadus morhua*), Atlantic halibut (*Hippoglossus hippoglossus*), wolffish (*Anarchias lupus*), anglerfish (*Lophius piscatorius*), and haddock (*Melanogrammus aeglefinus*), while pelagic species include mainly saithe (*Pollachius virens*) and Atlantic herring (*Clupea harengus*). Therefore, a Marine Protected Area (MPA) was established in 2013 to protect the marine habitats of Saltstraumen.

The inner Skjerstadfjord is about 50 km long with a basin of up to 530 m depth and the innermost fjord region was defined as the study area (Fig. 1). The water exchange between the two fjords Salt- and Skjerstadfjord occurs mainly through Saltstraumen resulting in an exchange of bottom water in the deep basins of Skjerstadfjord several times per year. Anoxic conditions, often observed in deep fjord basins (Holte et al., 2005), rarely take place in Skjerstadfjord and oxygen levels seem to remain relatively high throughout the year (Eliassen et al., 2001). Information about benthic communities and potential prey specie were not available for Skjerstadfjord, but we assumed a less diverse and abundant benthic community typically found in subtidal rocky habitats.

2.2 Citizen science approach and sampling

The sampling of fish stomachs in Saltstraumen and Skjerstadfjord took place from July until mid-September 2014. All stomach samples were collected as a part of a citizen science project. Although an all-encompassing definition of citizen science is not yet established, we understand citizen science as the “general public engagement in scientific research activities when citizens actively contribute to science either with their intellectual effort or surrounding knowledge or with their tools and resources" (European Commission, 2013). In our study, the public was mainly involved in the sampling and was encouraged to hand in the stomachs of fish caught in the study areas. Two main approaches were used here: a) all necessary equipment was provided at several collecting stations to enable people to independently hand in the samples, and b) the anglers at the sites were approached and we assisted in sampling or took the stomachs directly from their fish. Stomach samples were taken from the four demersal fish species cod, halibut, wolffish and haddock. Only the diet of cod was analysed in this study, because too few samples were received from the other species. Nevertheless, all species are included in the general qualitative assessment of the citizen science approach.

Four collecting stations were established in Saltstraumen and two in Skjerstadfjord (Fig. 1). The collecting stations were positioned at locations nearby the most popular fishing sites or at central locations for tourists such as a camping site and a fishing camp. At all stations, information about the project purpose and the different fish species were displayed on posters. In addition, leaflets explaining the sampling procedure (in Norwegian, English and German) were provided together with the sampling equipment. This equipment included a zip-lock plastic bag for the stomach with an attached sample sheet, a tape measure and a pencil. On the sample sheet the anglers were asked to enter date, time, fish species, fish length, type of fishing gear used (e.g. hand line, fishing rod), and to indicate the location of the catch on a map. The samples could be delivered into cooling boxes at the stations or freezers nearby. The cooling boxes were emptied and cool packs renewed several times a day to avoid warming of the samples. All samples were frozen as soon as possible (after maximum 5 h). The sampling campaign was publicised via the local newspapers, a project Facebook page and the university websites.

2.3 Sample processing

All samples with inaccurate information given on the sample sheets were omitted (see below). In the laboratory, the samples were carefully defrosted in a microwave. Large and very small stomachs were defrosted at room temperature to prevent overheating of the stomach content. Food items were sorted and identified to the lowest taxon possible, based on morphological characteristics. All taxa were counted and weighed (g wet weight) and samples were stored in 70% ethanol. Some prey taxa could only be identified through body parts, jaws or setae structures that were not yet digested. Whenever possible the number of individuals was here assessed based on the number of these structures (jaws of Polychaeta, eyes of Euphausiacea). Tissue samples for DNA barcoding analysis were taken from all prey fish and stored in 70% pure ethanol at -30°C.

2.4 DNA barcoding of fish prey

Fish is often identified as the most important prey in diet studies of cod (reviewed in Link et al., 2009). As the fish prey were often highly digested and difficult to identify, DNA barcoding was applied to verify or or enable determination of fish prey. Hence, DNA was extracted from a 2 mm cube of fish prey tissue (~10-15 mg) using DNeasy Blood & Tissue kit (Qiagen). DNA concentration was measured using NanoDrop 1000 Spectrophotometer (Thermo Fisher Scientific). PCR reactions targeted the 5' region of the mitochondrial cytochrome c oxidase 1 (COI) "barcoding" gene using the primer cocktail described by Ivanova et al. (2007). Amplifications were carried out using the Expand High Fidelity PCR system (Roche), in 25 µl volumes containing primers (0.5 µM of each), 1.5 mM $MgCl_2$, ~ 1.0 U of the enzyme, and ~150 ng template DNA. Negative controls were included in all runs. PCR products were sequenced on both strands using the BigDye Terminator v3.1 Cycle Sequencing Kit (Applied Biosystems). A maximum of 652 bp COI sequence was recovered for each specimen. Sequences were inspected and compiled using Chromas Lite 2.1.1 (Technelysium) and MEGA 6.06 (Tamura et al., 2013). Species designations were based on BLAST searching at NCBI, using the Megablast search option (Zhang et al., 2000) and at Barcode of Life Data Systems (Ratnasingham and Hebert, 2007). Because only fish tissue was used for DNA barcoding and the high fat content of some tissue samples was hampering the analysis with the approach used here, a relatively high proportion of the fish remained unidentifiable.

2.5. Statistical analyses

Four indices were calculated to analyse cod diet composition (based on Houlihan et al., 2001): the frequency of occurrence (FO), the relative abundance (A_N), the relative weight (A_W) and the relative importance index (RI). The frequency of occurrence (FO) is the percentage of stomachs in which the prey taxon occurs. The relative abundance (A_N) and weight (A_W) is the number or weight of a prey taxon as a percentage of all prey taxa. All three indices above give an indication of importance of taxa in the fish diet, but they will rank prey differently depending on their contribution in terms of numbers (A_N), weight (A_W) or occurrence (FO). In contrast, the relative importance index (RI) combines all three indices and is therefore considered as a more general index. It is calculated as a percentage of the total absolute importance index which is the sum of FO, A_N and A_W (Houlihan et al., 2001). For calculation of diet indices, cod length was grouped into four size classes (20-39 cm, 40-69 cm, 70-99 cm, ≥100 cm).

Relationships between cod length and prey abundance, prey weight and number of prey species were tested with non-parametric correlation analyses. Kendalls rank correlation coefficient (<tau>) measures the association between two variables based on rank orders between observations. All univariate analyses were performed using R version 3.1.2 (R Development Core Team, 2015).

Multivariate analyses were used to test for differences in diet composition depending on cod size classes and location based on prey abundance and biomass. An analysis of similarity randomisation test (ANOSIM) was used to test for significant differences in diet composition between locations and size classes, while Similarity Percentage analysis (SIMPER) identified the relative contribution of each prey taxon to the dissimilarities between compared groups (Clarke and Warwick, 2001). Prey abundance and biomass data were square-root transformed prior to analyses to reduce the effect of highly dominant prey items and (dis-)similarities were calculated using the Bray Curtis similarity index. All multivariate analyses were performed using PRIMER version 6.1.6 (Clarke and Warwick, 2001).

3. Results

Citizen science approach

The public sampling resulted in 455 stomach samples mainly from cod (371 samples), followed by haddock (45), halibut (28), and wolffish (11). About 31% of all samples were delivered independently, thus anglers used the provided equipment and delivered the samples without any further guidance except of an initial introduction to the sampling method. However, the two study areas differed remarkably regarding number of anglers. In Saltstraumen, a large number of anglers were present during summer and the majority of samples (about 80%) were acquired by assisted sampling where anglers were approached directly at the sites. In Skjerstadfjord, mainly local people and only few tourists contributed to the sampling, which is also reflected in the nationalities of contributors with participants from 10 countries in Saltstraumen and only three in Skjerstadfjord. Assisted sampling was only done occasionally in Skjerstadfjord due to the lack of personnel and most samples were handed in independently. Although the number of samples handed in independently was similar in both areas with 74 samples in Saltstraumen and 65 in Skjerstadfjord, they accounted for 69% of all collected samples in Skjerstadfjord. Erroneous or missing metadata were found in 14% of the independently delivered samples. Most often fish length was not measured (10%) or information on the exact catch location was missing (4%).

Cod diet composition

The analyses of the diet composition of cod stomachs is based on 229 stomach samples, with 59 samples from Skjerstadfjord (of which 24% were empty stomachs) and 170 from Saltstraumen (11% empty stomachs). In total, 109 prey taxa were found in the cod stomachs comprising 95 and 52 taxa in Saltstraumen and Skjerstadfjord, respectively. The multivariate analysis revealed a significant difference in the diet composition of cod between Saltstraumen and Skjerstadfjord both in terms of abundance (ANOSIM; $R = 0.122$, $p = 0.004$) and biomass ($R = 0.173$, $p = 0.001$).

In **Saltstraumen**, fish was the most important prey with a RI of 25% when all size classes were pooled (Table 1). Saithe (*Pollachius virens)* ($A_W = 23\%$) and Clupeidae ($A_W = 9\%$) were the main fish prey in the cod diet. Unidentified fish still accounted for 24% (A_W), while cannibalism on other cod was negligible in Saltstraumen ($A_W = 1\%$). The most important invertebrate groups in the cod diet were Ophiuroidea (RI = 16%), Brachyura (11%) and Polychaeta (7%), with *Ophiopholis aculeata* (Ophiuroidea), *Hyas coarctatus* and *Carcinus maenas* (Brachyura), and Polynoidae and Nereididae (Polychaeta) as the dominant taxa.

In **Skjerstadfjord**, fish also dominated the cod diet with a RI of 24% (Table 1), but here the cod mainly fed on other cod (A_W=16%) and Norway pout (*Trisopterus esmarkii*) ($A_W = 8\%$), with unidentified fish accounting for 18%. The invertebrate prey was mainly characterised by Echinoidea (RI = 9%), Polychaeta (8%), Bivalvia (7%) and Caridea (6%), with *Strongylocentrotus* spp. (Echinoidea), Polynoidae, Glyceridae and Onuphidae (Polychaeta), *Mytilus edulis* (Bivalvia), and *Pandalus* spp. (Caridea) as the dominant taxa. Notably, the planktonic Euphausiacea (A_N= 23%) and Mysidae (17%) were the most abundant prey taxon, but only occurred in less than 10% of the stomachs (Table 1).

Spatial difference in cod diet between size classes

Number of prey species, prey abundance and total stomach content weight per stomach varied with cod length (Fig. 2). In Saltstraumen, number of prey species ($\tau = -0.23$, $p < 0.001$) and prey abundance ($\tau = -0.30$, $p < 0.001$) decreased with cod length. Highest number of prey species and prey abundance was found in 40-69 cm cod. Total stomach content weight increased with cod length ($\tau = 0.29$, $p < 0.001$). In contrast, no significant correlation between cod length and number of prey species, prey abundance or total stomach content weight was found in Skjerstadfjord, probably because of too low sample sizes. Nevertheless, the highest number of prey species was found in 40-69 cm cod (Fig. 2b).

The cod size class of **20-39 cm** was only caught in Saltstraumen and the diet was dominated by fish with a RI of 35%. Saithe and unidentified fish were the most important fish prey. Also invertebrate prey was similar important in terms of weight (brachyuran crabs and Ophiuroidea) and relative abundance (Ophiuroidea and Caridea; Fig. 3).

The diet of **40-69 cm** cod significantly differed between Saltstraumen and Skjerstadfjord in terms of prey abundance (ANOSIM; $R = 0.139$, $p = 0.017$) and prey biomass ($R = 0.276$, $p = 0.001$). In Saltstraumen, the cod diet was dominated by Ophiuroidea (mainly *Ophiopholis aculeata)* with a RI of 20%, followed by fish (RI= 17%), mainly saithe ($A_W = 15\%$). Despite the high importance of Ophiuridea, fish prey was more important when measured by A_W or FO (Table 2). Other invertebrate prey of importance were Brachyura (RI = 12%; mainly *Hyas coarctatus*) and Polychaeta (8%). Also Caridea and Bivalvia were often preyed upon (Fig. 3; Table 2). In contrast, the cod diet in Skjerstadfjord was clearly dominated by fish with a RI of 27%, mainly Norway pout ($A_W = 22\%$) and cod (A_W=14%), followed by Mysidae (RI = 13%), Caridea (10%) and Polychaeta (10%; mainly *Heteromysis* cf. *formosa*). Despite relatively low RI values, Lithodidae and Echinoidea showed a comparatively high relative abundance in the diet (Fig. 3; Table 2).

Fish was the most important prey in the diet of the ***70-99 cm*** cod in both study areas, which differed significantly in diet composition (ANOSIM; abundance: $R = 0.134$, $p = 0.017$; biomass: $R = 0.119$, $p = 0.019$). In Saltstraumen, prey fish was found to account for a RI of 33%, with saithe ($A_W = 33\%$) and Clupeidae (13%) as the most important taxa. Invertebrate prey was mainly characterised by Holothuroidea (RI = 12%) and Brachyura (11%) (Fig. 3; Table 2). The cod in Skjerstadfjord was found to mainly feed on other cod (AW = 23%) with an overall importance of prey fish in the diet of 20% (RI). Invertebrate prey of high importance were Echinoidea (RI = 13%; mainly *Strongylocentrotus* spp.) and Bivalvia (12%; mainly *M. edulis*). Despite a low RI, Euphausiacea showed the highest relative abundance in the diet of cod in Skjerstadfjord (Fig.3).

The diet of the largest cod size class (≥**100 cm**) was clearly dominated by fish in both study areas, and only prey biomass significantly differed (ANOSIM; R = 0.373, p =0.003). In Saltstraumen, fish prey accounted for a RI of 77% (Table 2), while all other prey taxa contributed less than 6% RI. Saithe (A_W = 16%) and Clupeidae (11%) were the most important fish prey, but the major part of 68% (A_W) were unidentified fish. In Skjerstadfjord, fish also showed the highest RI with 38% in the cod diet. Lithodidae were the second most important prey (RI = 29%; AW = 58%; *Lithodes maja*), but they were only found in one of the seven cod stomachs.

4. Discussion

The study area Saltstraumen with its strong tidal currents is characterised by a highly diverse invertebrate and fish fauna (Fagerli et al., 2015) and we hypothesised that the high abundance of especially invertebrate prey in Saltstraumen significantly affects the diet composition of NCC cod. Indeed, the cod diet showed significant small-scale differences in the prey composition within the fjord ecosystem, despite the limited number of samples acquired during the citizen science sampling campaign. The most important prey was fish in almost all cod size classes (based on RI) with the highest proportion in the largest cod. This is consistent with the described ontogenetic shift showing an increase in the proportion of fish prey with increasing cod length (Link and Garrison, 2002). However, cod of all size classes also fed to a relatively high amount on invertebrate prey and specifically echinoderms and crustaceans caused the differences in the diet of intermediate sized cod between the two study areas. In Saltstraumen, brittle stars (Ophiuroidea), sea cucumbers (Holothuroidea) and crabs (Brachyura) were an important food source, while in Skjerstadfjord sea urchins (Echinoidea), bivalves and planktonic crustaceans (Mysida and Euphausiacea) were additional prey for intermediate sized cod (Table 2). Contrary to our hypothesis, the highly abundant sessile fauna of Saltstraumen, such as Actinaria, soft corals and Holothuroidea, was rarely found in the cod stomachs except of Holothuroidea mainly in the cod size class of 70-99 cm.

4.1. Small-scale differences in cod diet composition

When all size classes were pooled, the diet of cod was mainly dominated by fish and to lesser extent by crustaceans in Saltstraumen and Skjerstadfjord (Table 2). This is consistent with findings of cod diet composition in the North-East Atlantic, where the proportion of fish and crustacean prey varied considerably between regions (Du Buit, 1995; Jaworski and Ragnarsson, 2006; Klemetsen, 1982; Magnussen, 2011; Pachur and Horbowy, 2013) as well as between seasons (Hop et al., 1992; Salvanes and Nordeide, 1993). Although fish was the dominant prey in both study areas, the species composition of fish prey varied. The most important fish prey in Saltstraumen was saithe (*Pollachius virens)*, which is highly abundant in this area and often targeted by recreational anglers, followed by clupeids. In other regions, clupeids were the primary prey for cod with a proportion of up to 67% (A_W) (Baltic Sea; Pachur and Horbowy, 2013). Along the Norwegian coast, clupeids and capelin were also important prey in northern fjords (Hop et al., 1992; Kanapathippillai et al., 1994), but capelin does not occur in our study region. In contrast, gobies and wrasses were more important prey in southern and western regions (Hop et al., 1992). Although clupeids seemed to be only of moderate importance as prey in Saltstraumen (A_W = 9%) and were not found in Skjerstadfjord, large numbers of small clupeids migrated into Saltstraumen during the last days of sampling (own observations), indicating a shift in prey availability depending on the season. Indeed, a shift in cod diet towards Atlantic herring and Atlantic mackerel was observed in the Northwest Atlantic, when schools of these species migrated into the region (Smith et al., 2007). In Skjerstadfjord, on the other hand, *Gadus morhua* (A_W = 16%) and *Trisopterus esmarkii* (8%) were the most important fish prey. Cannibalism in cod is common in many regions, with the highest proportion in large cod (Bogstad et al., 1994). In the Barents Sea, Icelandic and Newfoundland waters, cannibalism accounted for 0-9% (A_W) (Bogstad et al., 1994; Yaragina et al., 2009), while up to 80% (A_W) was found for cod larger than 60 cm in Northern Norway (Kanapathippillai et al., 1994). The occurrence of cannibalism is often related to the abundance of juvenile cod (Bogstad et al., 1994), which might also explain the relatively high proportion of cannibalism in Skjerstadfjord, where several spawning sites are situated (Dahle and Meeren, 2014).

Compared to NEAC in the Barents Sea, which mainly feed on capelin and several other fish species (Dolgov et al., 2008; Durant et al., 2014), the diet of NCC in northern fjords seem to be more diverse with a larger proportion of invertebrate benthic prey (Kanapathippillai et al., 1994). So far, invertebrates were shown to be mainly important for small and intermediate sized cod (Link and Garrison, 2002; Svåsand et al., 2000), but in our study even the size class 70-99 cm cod consumed more than 40% invertebrates in terms of weight. The invertebrate prey also mainly caused the differences in diet composition between the two areas, with brittle stars, crabs and sea cucumbers predominantly fed on in Saltstraumen, while sea urchins, bivalves, shrimps and krill were more often fed on in Skjerstadfjord (Table 1 and 2). While crustaceans are known to be an important prey for cod (e.g. Du Buit, 1995; Link and Garrison, 2002; Svåsand et al., 2000), echinoderms were rarely reported to be a significant food source for cod (but see Kanapathippillai et al., 1994; Mello and Rose, 2005), but in Saltstraumen brittle stars were among the most important prey for 40-69 cm cod (RI = 19%). Although other benthivore gadoid species (e.g. haddock) frequently feed on echinoderms (Jaworski and Ragnarsson, 2006; Schückel et al., 2010), echinoids and ophiuroids represent an energy-poor food source (Brey, 2001). It seems unlikely that ophiuroids in Saltstraumen were eaten because of food limitation, with the high abundance of fish and invertebrates in this area. Also Kanapathippillai et al. (1994) found ophiuroids in large quantities in cod of the same size class in Sørfjord, which raises the question why cod is feeding on this food source when high-energy prey is available? This seem to contradict the optimal foraging theory, which suggests that the largest prey available should be consumed to maximise energy uptake (Schoener 1971; Scharf et al. 2000). On the other hand, ophiuroids are an easily accessible prey due to their hemi-sessile life mode and in areas with strong currents such as Saltstraumen, near bottom feeding on ophiuroids might be energetically favourable. The relatively low energy gain would be compensated by the low costs of foraging (Scharf et al. 2000). Also in Sørfjord, ophiuroids were mainly found in the diet of cod close to a tidal inlet with strong currents. In Skjerstadfjord, the second most important prey for 70-99 cm cod were echinoids (RI = 13%), mainly the green sea urchin *Strongylocentrotus* spp.. To our knowledge, only Harding and Hutchings (2011) reported that landlocked cod is feeding on green sea urchins in the Canadian Arctic, while this was not found for the stocks in the NE Atlantic regions until now. Fagerli et al. (2014) showed that mainly crabs feed on the green sea urchin, but they found no indication that they were eaten by the highly abundant cod. Our observation might have ramifications for the recovery dynamics of kelp forests along the Norwegian coast, which almost vanished during the 1980s caused by sea urchin grazing, and only slowly recovered thereafter (Rinde et al., 2014; Sivertsen, 1997). Cod as a key stone species in the food web of northern fjords (Pedersen et al., 2008), potentially induces cascading effects, if sea urchins are frequently used as a food source, at least on a local scale.

The general question remains whether the small-scale differences in the diet observed in this study have consequences for the local cod populations? Differences in cod diet can affect growth and fish condition (Mello and Rose, 2005; Mullowney and Rose, 2014), but on small spatial scales the cod might compensate differences in food availability by migrating within or between fjords. However, we found indications for a shortage of high-quality food in Skjerstadfjord compared to Saltstraumen. In Skjerstadfjord, the proportion of fish in the diet was lower, while the proportion of energy-poor echinoids was high, especially in the larger size classes, which are expected to mainly feed on fish. Furthermore, the rate of empty stomachs (24%) was twice as high as in Saltstraumen (11%) and cannibalism occurred more often, which might also indicate the lack of alternative prey (Mehl, 1991). Unfortunately, the number of samples in our study is too low to draw general conclusions and the condition of cod could not be assessed during the citizen science sampling.

4.2 Citizen Science approach

Our study demonstrated the potential use of citizen science, where volunteers "collect and/or processes data as part of a scientific enquiry" (Silvertown, 2009), for studying coastal fish populations and their diet, although the sampling was less efficient in terms of acquired samples than scientific surveys. Within the natural sciences, citizen science was mainly used in terrestrial systems for a variety of research topics ranging from bird monitoring to evolutionary questions (reviewed in Dickinson et al., 2012). Since recently, the approach is increasingly used for monitoring marine ecosystems e.g. sea grass beds (Seagrass Watch, 2016) or marine invasive species (MITIS, 2016), aiming at data collections on spatial and temporal scales that regular monitoring cannot accomplish. Our approach, in contrast, was focusing on the local scale.

There are of course limitations when research is based on non-expert contributions, which were also experienced in our study. Quality control of the sampling procedures and accuracy of the meta-data are important issues that need to be addressed (Aceves-Bueno et al., 2015). In our study, about 14% of the samples handed in independently were lacking information e.g. about fish length or sampling position, while other important meta-data such as fish weight, sex or condition were not asked for because of logistical difficulties. In addition, the potential inaccuracy of the provided records has contributed to a higher variability of the meta-data. Variation in the handling time of fish by the anglers might have also affected the stomach data quality. Indeed, the biomass of easily digestible prey such as polychaetes was underestimated, since in some cases only jaws, setae or other skeletal structures made the recording of the taxa possible, but not the biomass determination. In addition, the relatively low rate of independently handed in samples of 30%, emphasise the need for a trained personnel to support such a citizen science campaign.

In coastal and fjord systems, regular scientific monitoring is rarely done and often limited by the available financial or technical resources, and citizen science might provide an alternative way to collect monitoring data, which otherwise would not be available (Aceves-Bueno et al., 2015). Furthermore, there is no monitoring of recreational fisheries on NCC in Norwegian fjords, which increases the uncertainties related to the NCC management (ICES, 2015), while declining NCC stocks in the last decade indicate the need for a separate management of local sub-populations (Reiss et al., 2009). Thus, despite its limitations, citizen science might be an additional tool to be integrated into adaptive management of coastal fish stocks or marine spatial planning that require local stakeholder involvement (Aceves-Bueno et al., 2015; Jarvis et al., 2015), but the management need for robust data has to be aligned with the potential inaccuracy of citizen science derived data.

4.3 Conclusion

The differences in cod diet found within the fjord system Saltfjord-Skjerstadfjord was mainly caused by invertebrate prey, which substantially contributed to the diet even of large sized cod. However, the dominant sessile hard bottom fauna of Saltstraumen was rarely found in the stomachs except of Holothuroidea. To what extent these small-scale differences in the diet translate into consequences for the local cod populations remains unclear, although our results may indicate a shortage of high quality food in Skjerstadfjord, but these results have to be interpreted with care, because of the relatively low number of samples in our study.

Nevertheless, the NCC in fjords seems to feed to a larger extent on invertebrate prey than for example the NEAC in the Barents Sea (Dolgov et al., 2008; Kanapathippillai et al., 1994). Thus, changes in the invertebrate fauna in fjords caused by e.g. climate change, fish farming, or natural variability may in turn affect higher trophic levels such as the keystone species cod. Unfortunately, faunal data of fjord ecosystems for both invertebrate benthos as well as fish are often meagre, which makes it difficult to assess these changes as well as their potential consequences. Our study indicated that citizen science might provide here an additional tool to acquire monitoring data and at the same time involve the public into scientific projects, although sample collection was less efficient than scientific surveys. Co-management approaches that are based on the devolution of management authority to local fishing communities (Hilborn et al., 2005), might be a suitable framework for such a public participation and management decisions that are at least partly based on contributions by the local people, may receive more acceptance.

Acknowledgement

We thank all people who have contributed to the citizen science sampling. Thanks to Bjørn Tore Zahl from Saltstraumen Brygge, Geir Jøran Nyheim from Saltstraumen camping, Lill-Anita Stenersen from Kafe Kjelen as well as Fauske Båtforening and Saltdal Båtforening for their logistic support during sampling. We also appreciated the help of Truls Moum, Martina Kopp and Vigdis Edvardsen with the DNA barcoding. Thanks to Katrin Reiss and the reviewers for valuable comments to improve the manuscript.

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MARSYS-D-16-00066

Diet of Norwegian coastal cod (*Gadus morhua*) studied by using citizen science

Siri Elise Enoksen and Henning Reiss

<u>Figures</u>

Figure 1. Location of the study areas Saltstraumen (small box) and Skjerstadfjorden (large box) in the fjord system (position of collecting stations indicated).

Figure 2. Number of prey species (a), prey abundance (b) and weight (c) of total stomach content of the different size classes of cod in Saltstraumen and Skjerstadfjorden. Number of stomachs analysed is given in parentheses.

Figure3. Relative diet composition of cod based on abundance (a) and biomass (b) of the different prey taxa.

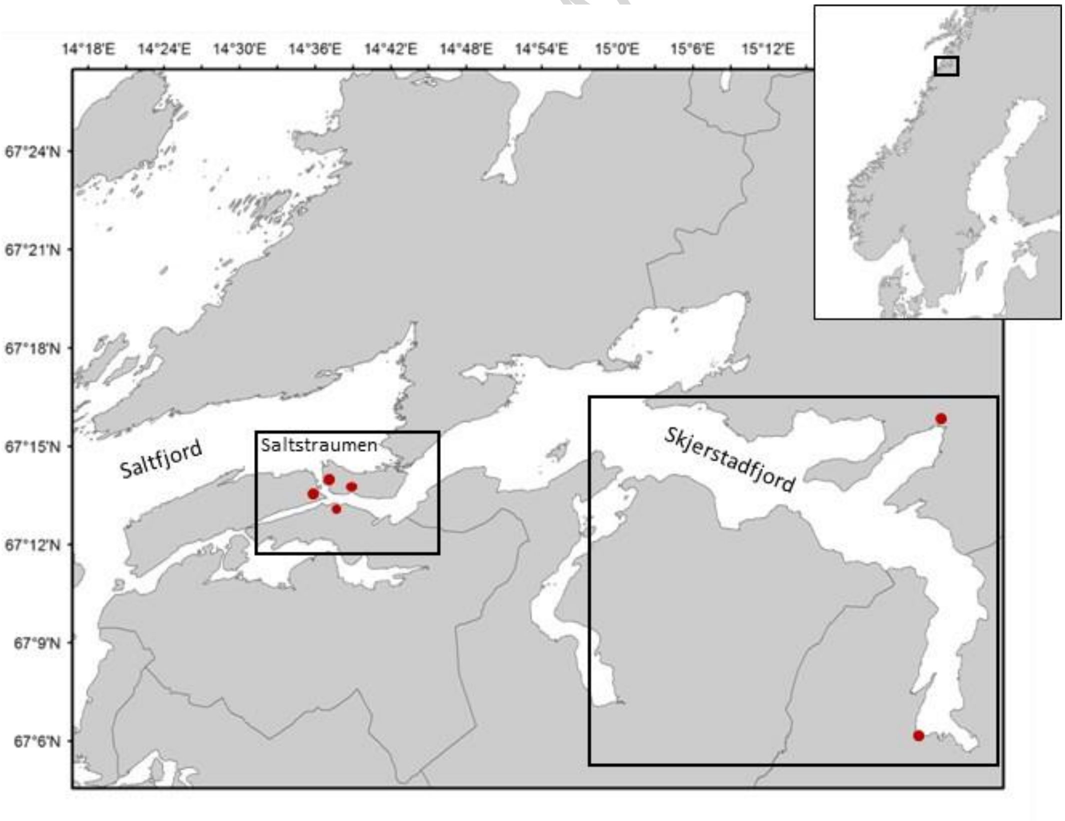
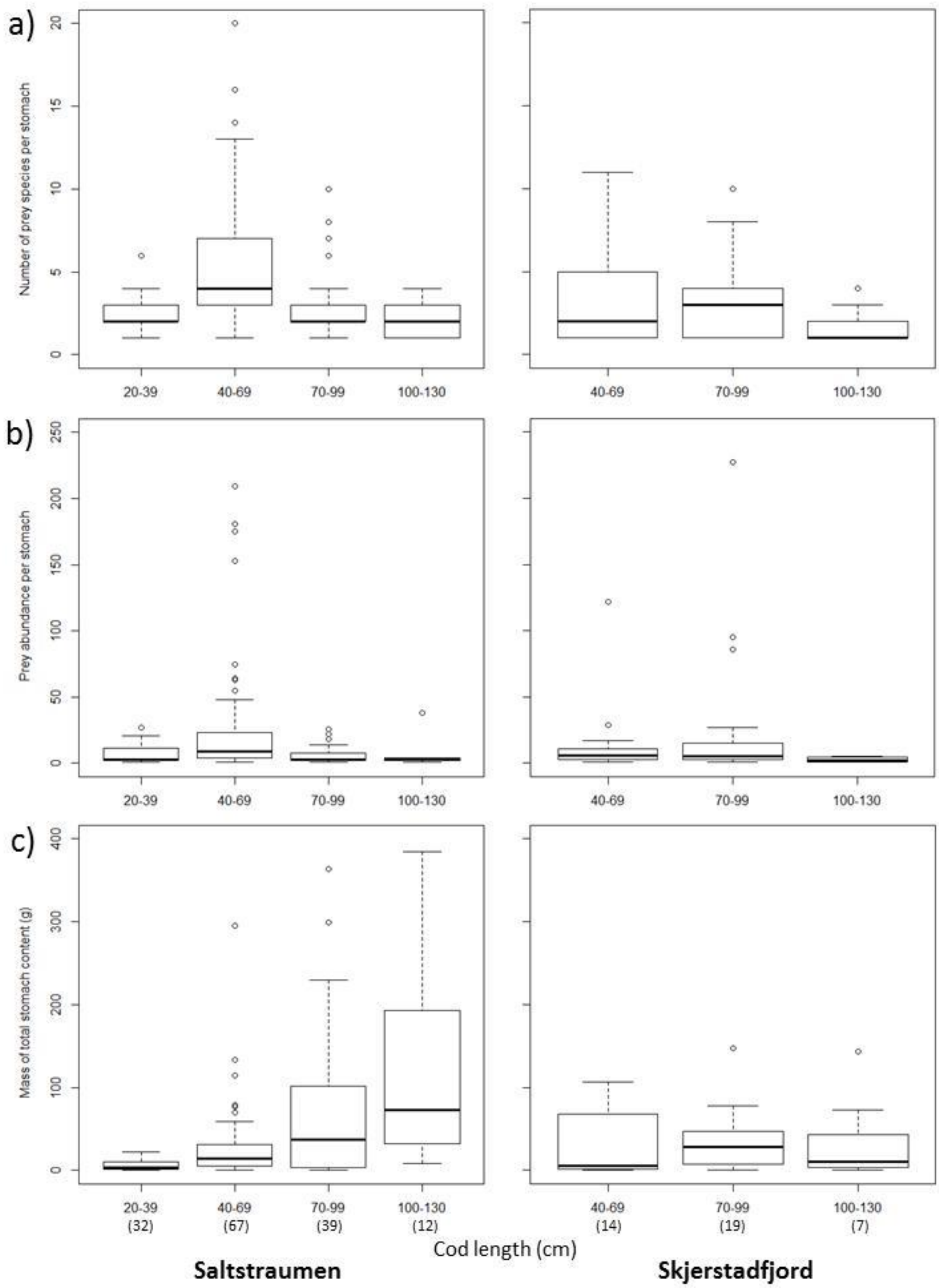
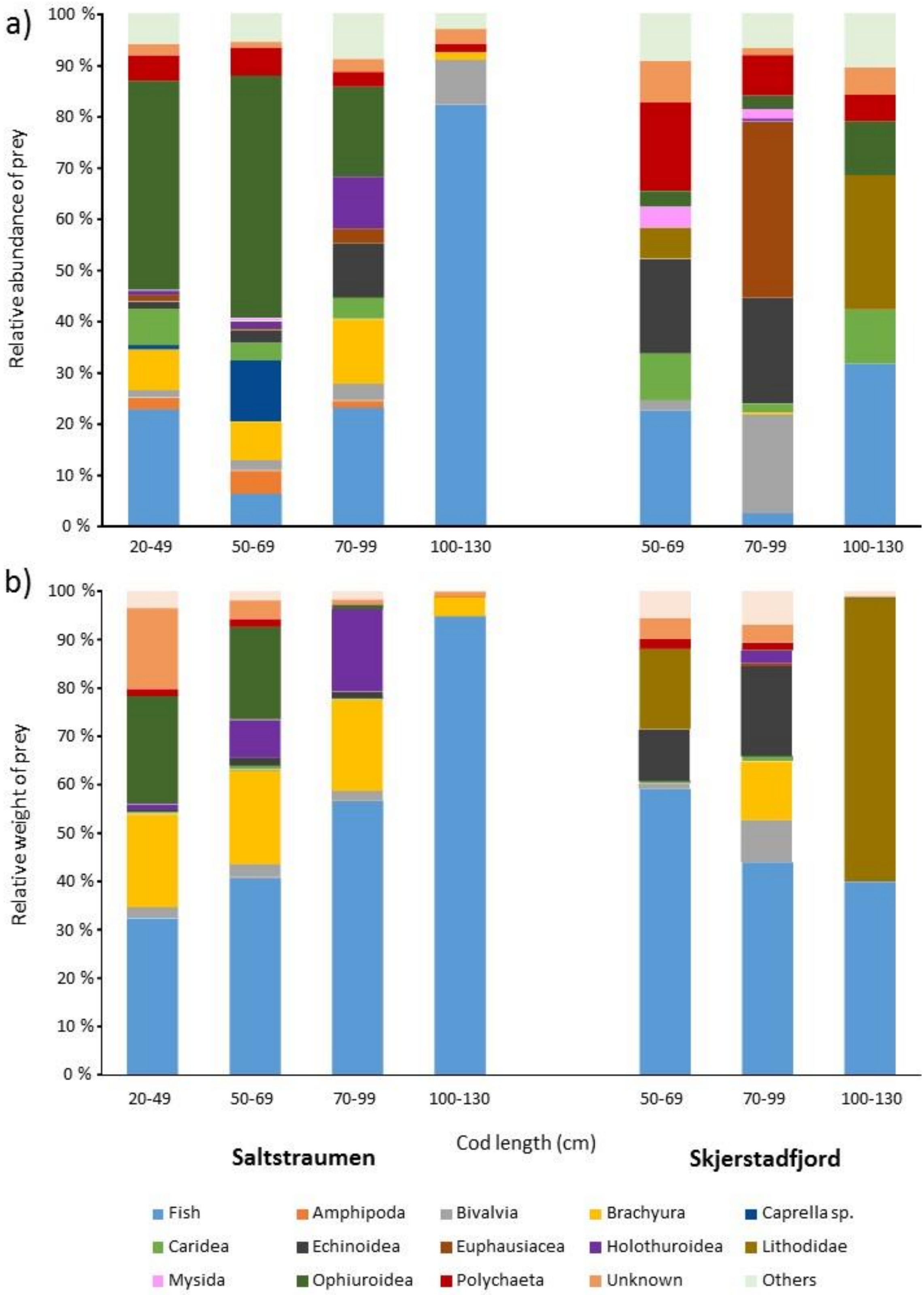


Figure 1



a)
Number of prey species per stomach
0
5
10
15
20
20-39
40-69
70-99
100-130
b)
Prey abundance per stomach
0
50
100
150
200
250
c)
Mass of total stomach content (g)
0
100
200
300
400
20-39 (32)
40-69 (67)
70-99 (39)
100-130 (12)
40-69 (14)
70-99 (19)
100-130 (7)
Cod length (cm)
Saltstraumen
Skjerstadfjord

Figure 2



a)
Relative abundance of prey
100 %
90 %
80 %
70 %
60 %
50 %
40 %
30 %
20 %
10 %
0 %
20-49
50-69
70-99
100-130
50-69
70-99
100-130
b)
Relative weight of prey
Cod length (cm)
Saltstraumen
Skjerstadfjord
Fish
Amphipoda
Bivalvia
Brachyura
Caprella sp.
Caridea
Echinoidea
Euphausiacea
Holothuroidea
Lithodidae
Mysida
Ophiuroidea
Polychaeta
Unknown
Others

Figure 3

MARSYS-D-16-00066

'Diet of Norwegian coastal cod (*Gadus morhua*) studied by using citizen science'

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Tables

Table 1. Prey taxa in the diet of cod with relative frequency of occurrence (FO), relative abundance (A_N), relative weight (A_W), and relative importance index (RI), and results of SIMPER (contribution to dissimilarities between areas) for Saltstraumen and Skjerstadfjord. The five highest values are indicated in bold and number of stomachs is given in parentheses (*unidentified).

	Saltstraumen (150)				Skjerstadfjord (47)				SIMPER
Taxa	**FO**	**A_N**	**A_W**	**RI**	**FO**	**A_N**	**A_W**	**RI**	**Contribution (%)**
Fish	**65.3**	**13.1**	**58.7**	**25.0**	**60.5**	5.4	**48.0**	**24.0**	1.7
Ophiuroidea	**38.7**	**41.9**	**7.5**	**16.1**	**16.3**	2.8	0.2	4.1	1.9
Brachyura	**36.0**	**8.0**	**15.7**	**10.9**	7.0	0.5	**5.8**	2.8	8.0
Polychaeta	**32.0**	**5.0**	0.6	**6.9**	**30.2**	**7.6**	1.4	**8.3**	8.6
Holothuroidea	17.3	2.1	**9.4**	**5.2**	7.0	0.5	1.3	1.9	3.7
Caridea	**24.0**	4.2	0.4	5.2	**25.6**	3.7	0.7	**6.3**	7.4
Bivalvia	22.0	2.2	1.8	4.8	18.6	**13.1**	**4.6**	**7.6**	6.8
Unknown	21.3	1.5	**3.0**	4.7	**23.3**	2.2	3.4	6.1	6.2
Amphipoda	13.3	3.7	0.0	3.1	2.3	0.1	0.0	0.5	2.9
Caprella sp.	8.7	**8.3**	0.0	3.1	-	-	-	-	4.4
Gastropoda	13.3	1.3	0.4	2.7	16.3	1.0	1.8	4.0	3.2
Echinoidea	9.3	3.0	1.1	2.4	14.0	**15.9**	**12.4**	**8.9**	6.4
Galatheoidea	9.3	0.9	0.2	1.9	-	-	-	-	-
Paguroidea	8.0	0.6	0.2	1.6	9.3	1.0	0.2	2.2	2.2
Decapoda*	7.3	0.5	0.1	1.4	7.0	0.4	0.0	1.6	-
Isopoda	4.0	1.2	0.0	0.9	-	-	-	-	-
Balanomorpha	4.0	0.5	0.2	0.9	-	-	-	-	-
Euphausiacea	2.7	0.8	0.0	0.6	2.3	**22.8**	0.2	5.3	-
Crustacea*	2.7	0.2	0.0	0.5	4.7	0.3	0.0	1.0	-
Porifera	2.0	0.1	0.0	0.4	2.3	0.1	1.2	0.8	-
Hyperiidea	2.0	0.1	0.0	0.4	2.3	0.6	0.0	0.6	-
Nemertea	1.3	0.1	0.0	0.3	-	-	-	-	-
Mysida	0.7	0.3	0.0	0.2	9.3	**17.3**	0.3	5.7	-
Ascidiacea	0.7	0.1	0.1	0.2	9.3	3.1	2.4	3.1	2.7
Actiniaria	0.7	0.1	0.2	0.2	-	-	-	-	-
Lithodidae	0.7	0.0	0.0	0.1	4.7	1.4	**16.2**	4.7	2.0

Table 2. Prey taxa in the diet of cod per size class with relative frequency of occurrence (FO), relative abundance (A_N), relative weight (A_W), and relative importance index (RI). The five highest values are indicated in bold and number of stomachs given in parentheses (* unidentified). Fish prey is shown separated into the most important species and unidentified fish.

	40 – 69 cm								70 – 99 cm								≥100 cm							
Prey taxa	**Saltstraumen (87)**				**Skjerstadfjord (17)**				**Saltstraumen (39)**				**Skjerstadfjord (19)**				**Saltstraumen (12)**				**Skjerstadfjord (7)**			
	FO	**A_N**	**A_W**	**RI**	**FO**	**A_N**	**A_W**	**RI**	**FO**	**A_N**	**A_W**	**RI**	**FO**	**A_N**	**A_W**	**RI**	**FO**	**A_N**	**A_W**	**RI**	**FO**	**A_N**	**A_W**	**RI**
Fish (total)	**59.8**	**8.6**	**38.4**	**16.9**	**70.6**	**9.8**	**57.8**	**27.0**	**69.2**	**23.1**	**56.6**	**32.8**	**52.6**	2.3	**43.8**	**20.2**	**100**	**82.1**	**94.7**	**77.2**	**57.1**	**31.6**	**39.8**	**37.5**
Clupeidae	8.0	2.5	4.2	2.0	-	-	-	-	15.4	4.2	12.7	6.6	-	-	-	-	25.0	6.0	11.0	10.3	-	-	-	-
G. morhua	3.4	0.2	3.7	1.0	5.9	0.4	14.4	3.8	-	-	-	-	5.3	0.2	23.0	5.5	-	-	-	-	-	-	-	-
P. virens	6.9	0.6	14.5	3.0	-	-	-	-	15.4	4.2	33.1	10.8	-	-	-	-	33.3	6.0	15.9	13.5	-	--	-	-
H. platessoides	-	-	-	-	-	-	-	-	-	-	-	-	5.3	0.2	3.4	1.7	-	-	-	-	-	-	-	-
H. hippoglosus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14.3	5.3	4.0	6.4
P. gunnellus	11.5	0.7	3.2	2.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T. esmarkii	-	-	-	-	5.9	0.8	22.3	5.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
unidentified fish	42.5	4.5	12.4	8.2	52.9	8.1	20.9	15.2	46.2	13.4	10.0	14.2	36.8	1.7	9.8	9.3	91.7	70.1	67.8	56.2	57.1	26.3	35.8	32.1
Ophiuroidea	**54.0**	**46.8**	**19.6**	**19.1**	17.6	2.4	0.1	3.9	**20.5**	**17.6**	0.9	**8.6**	15.8	2.7	0.2	3.8	-	-	-	-	**14.3**	**10.5**	0.2	**7.3**
Lithodidae	1.1	0.0	0.1	0.2	5.9	2.4	**16.3**	4.8	-	-	-	-	-	-	-	-	-	-	-	-	**14.3**	**26.3**	**58.4**	**28.9**
Brachyura	**49.4**	**7.7**	**19.6**	**12.1**	11.8	0.8	0.2	2.5	**20.5**	**12.6**	**18.8**	**11.4**	5.3	0.4	**12.1**	3.6	**8.3**	1.5	4.1	3.9	-	-	-	-
Caridea	**29.9**	4.1	0.8	5.5	**41.2**	**7.3**	0.5	**9.6**	15.4	4.2	0.4	4.4	15.8	1.7	1.1	3.8	-	-	-	-	**14.3**	**10.5**	0.1	**7.3**
Polychaeta	**44.8**	**5.3**	1.7	**8.2**	**41.2**	**7.3**	2.1	**9.9**	12.8	2.9	0.1	3.5	**26.3**	**7.9**	1.4	**7.3**	**8.3**	1.5	0.0	2.8	**14.3**	5.3	0.0	5.7
Echinoidea	13.8	2.3	1.5	2.8	5.9	**7.3**	**10.5**	4.6	5.1	**10.5**	1.4	3.7	**26.3**	**20.6**	**18.6**	**13.4**	-	-	-	-	-	-	-	-
Bivalvia	26.4	1.9	2.7	4.9	11.8	0.8	1.2	2.7	**17.9**	3.4	2.1	**5.2**	**31.6**	**19.4**	**8.8**	**12.2**	**8.3**	**9.0**	0.0	4.8	-	-	-	-
Mysida	1.1	0.3	0.0	0.2	11.8	**51.2**	0.8	**12.5**	-	-	-	-	10.5	1.9	0.1	2.6	-	-	-	-	-	-	-	-
Unknown	26.4	1.3	**6.5**	5.4	17.6	3.7	**4.6**	5.1	12.8	2.5	1.1	3.6	**31.6**	1.3	3.6	**7.5**	**16.7**	3.0	1.0	**5.8**	14.3	5.3	0.5	5.8
Holothuroidea	16.1	1.2	**6.7**	3.8	5.9	0.4	0.2	1.3	**25.6**	**10.1**	**16.9**	**11.6**	10.5	0.6	2.7	2.8	-	-	-	-	-	-	-	-
Caprella sp.	12.6	**9.8**	0.1	3.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Euphausiacea	2.3	0.6	0.0	0.5	-	-	-	-	5.1	2.9	0.0	1.8	5.3	**34.4**	0.5	8.2	-	-	-	-	-	-	-	-
Gastropoda	16.1	1.1	0.3	2.8	**23.5**	1.6	**5.0**	**5.9**	10.3	2.5	0.6	3.0	15.8	0.8	0.1	3.4	8.3	1.5	0.1	2.8	-	-	-	-

Table 2. continued

Prey taxa	40 – 69 cm								70 – 99 cm								≥100 cm							
	Saltstraumen (87)				Skjerstadfjord (17)				Saltstraumen (39)				Skjerstadfjord (19)				Saltstraumen (12)				Skjerstadfjord (7)			
	FO	A_N	A_W	RI	FO	A_N	A_W	RI	FO	A_N	A_W	RI	FO	A_N	A_W	RI	FO	A_N	A_W	RI	FO	A_N	A_W	RI
Paguroidea	9.2	0.4	0.5	1.6	**23.5**	3.3	0.5	5.3	10.3	2.1	0.2	2.8	-	-	-	-	-	-	-	-	-	-	-	-
Ascidiacea	1.1	0.1	0.4	0.3	5.9	0.4	0.3	1.3	-	-	-	-	10.5	**4.0**	**4.4**	3.9	-	-	-	-	14.3	**10.5**	1.0	**7.5**
Amphipoda	18.4	4.2	0.1	3.6	5.9	0.4	0.0	1.2	7.7	1.3	-	2.0	-	-	-	-	-	-	-	-	-	-	-	-
Galatheoidea	14.9	1.0	0.5	2.6	-	-	-	-	2.6	0.4	0.0	0.7	-	-	-	-	-	-	-	-	-	-	-	-
Decapoda*	10.3	0.5	0.3	1.8	5.9	0.4	0.0	1.2	5.1	0.8	-	1.3	10.5	0.4	0.1	2.2	-	-	-	-	-	-	-	-
Isopoda	6.9	1.4	0.0	1.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hyperiidea	-	-	-	-	-	-	-	-	7.7	1.3	0.0	2.0	5.3	1.0	0.0	1.3	-	-	-	-	-	-	-	-
Crustacea*	3.4	0.2	0.0	0.6	5.9	0.4	0.0	1.2	-	-	-	-	5.3	0.2	0.0	1.1	8.3	1.5	0.0	2.7	-	-	-	-
Porifera	3.4	0.1	0.0	0.6	-	-	-	-	-	-	-	-	5.3	0.2	2.5	1.6	-	-	-	-	-	-	-	-

Highlights

MARSYS-D-16-00066

'Diet of Norwegian coastal cod (*Gadus morhua*) studied by using citizen science'

Siri Elise Enoksen and Henning Reiss

- Diet of Norwegian coastal cod was studied with public involvement (citizen science)
- Small-scale differences of cod diet were found within a fjord system
- Invertebrate prey contributed with more than 40% to the diet of cod up to 99 cm
- Highly abundant sessile fauna were of minor importance as prey