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Samandrag

Atlantisk makrell er kjent for å vera opportunistisk i sitt fødeinntak, og dei siste åra har bastanden hatt ein kraftig ekspansjon i beiteområdet sitt mot nord. Ein har derfor stilt seg spørsmålet om makrellbeiting kan påverka overlevinga hos sildelarvane som driv nordover langs norskekysten seint på våren. Dette studiet undersøker overlappen i utbreiing mellom makrell og sildelarvar, samt dietten til makrell langs norskekysten mellom 66° og 69°N. Undersøkingane blei gjort i starten av juni 2013, og eit kursnett med hyppige prøvetakingsstasjonar blei repetert to gonger.

Resultata viste at makrell var fordelt over heile studieområdet, men i lause konsentrasjonar og nær overflata. Under rutineovervakingstoktet ein månad tidlegare var makrell ikkje registrert i studieområdet. Sildelarvane på den andre sida, var meir talrike i nord enn i sør, meir talrike under første enn andre dekning og endå meir talrike, særleg i sør, under overvakingstoktet ein månad tidlegare.

Hoppekreps og særleg raudåte var samla sett dei viktigaste byttedyra til makrellen, men sildelarvar stod for høvesvis 23 og 6.5 % av det totale fødekonsumet under dei to dekningane. 45 % av makrellmagane inneheldt sildelarvar, med 225 som høgste registrerte antal i ein einsleg mage. Resultata indikerer vidare at både mengda av larvar i magane og andelen av makrellmagar som inneheldt larvar auka med tilgjenget på larvar. Det blei derimot ikkje funne nokon samanheng mellom mengda av makrell og mengda av sildelarvar. Dette tyder på at makrellen ikkje selektivt jagar sildelarvar på regional skala, men at beitinga på larvar heller er opportunistisk.

Svært grovt estimert vil makrellen, gitt den overlappen i fordeling og det konsumet som blei observert under vår første dekning, vera i stand til å beita ned larvane i studiområdet på 9 dagar. Sjølv om det store fleirtalet av larvane etter alt å døma på dette tidspunktet var ute av området, illustrerer det beiteeffektiviteten og poengterer at innverknaden makrell kan ha på sildelarvar er heilt avhengig av graden av overlapp mellom desse artane i tid og rom. Overlappen i 2013 var truleg begrensa sidan våre resultat tyder på at makrellen kom inn i vandringsbana til sildelarvane på eit relativt seint tidspunkt.

Summary

Atlantic mackerel is an opportunistic feeder and with the recent expansion in distribution area during feeding, its potential predatory impact on herring larvae has been debated. In the present study we investigate the overlap in distribution between mackerel and herring larvae along the Norwegian coastal shelf with the main focus between ca. 66°N to 69°N in the beginning of June 2013, and investigate the mackerel prey consumption. A zig-zag transect with stations for sampling mackerel and herring larvae each 20 n.mile was conducted twice.

Our results showed that mackerel were distributed in the entire study area, but dispersed and close to the surface. During the regular monitoring survey conducted a month earlier,

mackerel was not observed north of 66°N. Herring larvae, on the other hand, was much more abundant during the monitoring survey. By the time of our survey, there were still larvae left, but more in the north than in the south and more during the first than the second leg, suggesting that larvae had already drifted out of the survey area.

Calanoid copepods were the most important prey of the mackerel, but herring larvae constituted 23 and 6.5 % of the diet during first and second coverage, respectively, and 45 % of the mackerel guts contained herring larvae, with 225 as the maximum number of larvae counted in a single gut. Furthermore, our results indicate that both the average amount of larvae in the gut and the frequency of mackerel larvae in the guts increased with increasing amount of larvae, while there was no relationship found between the amount of mackerel and the amount of larvae. This suggests that mackerel feed opportunistically on herring larvae, and therefore may have a huge impact on larval survival, largely depending upon the degree of overlap in time and space. For 2013, our results indicate that the overlap was limited since mackerel arrived late in the larvae drift trajectory.

Background

The North East Atlantic mackerel (*Scomber scombrus*) population has in recent years expanded its distribution area northwards and may now be common along the Norwegian coast up to the polar circle and beyond already in May. Mackerel are opportunistic animals and use both filter feeding and particulate feeding to prey upon a range of organisms from calanoid copepods via amphipods and krill to small fish and larvae (Iversen, 2004; Prokopchuk & Sentyabov 2006). In recent years, the expanded distribution area has resulted in periodical spatial overlap between mackerel and newly hatched larvae of Norwegian Spring Spawning herring (NSS-herring; *Clupea harengus*). No strong year-classes have been observed in NSS-herring after 2004 and a concern that the changed mackerel distribution has resulted in high predation pressure and reduced year class strength of NSS-herring has been expressed by the fisheries industry as well as by scientists. Based on this concern, the Institute of Marine Research with funding contributions from Norges sildesalgslag, extended the regular Norwegian Sea monitoring survey in May/June 2013 to investigate mackerel feeding on herring larvae.

Considering the time available for investigations, survey effort was allocated to a limited area expected to be at the core of herring larvae distribution at the time of the investigations. Based on frequent sampling of mackerel and mackerel stomachs, herring larvae and mesozooplankton, the investigations aimed at elucidating several aspects of herring larval predation by mackerel, including estimating total consumption, incidence of larvae feeding and potential selective feeding on larvae.

Material and methods

Vessel and survey design

The survey was conducted on board R/V ‘Johan Hjort’ along a pre-defined transect across a shelf edge in the herring larvae distribution area (See Figure 1). Stations were carried out at fixed positions with regular spacings of 20 nautical miles (n.miles). Originally, the plan was to run zig-zag transect lines down to approximately 63° N, but already north of 66° N the herring larvae abundance was so low that it was considered more appropriate to repeat the first transect a second time.

Data collection

On every station a Conductivity Temperature Depth (CTD)-cast was carried out to bottom depth as well as a haul with the larvae/juvenile sampler Methot Isaac Kidd (MIK) down to 100 m. Plankton sampling was carried out with WP2 net (180 µm mesh) down to 200 m on every second station together with samples of water. Acoustic data were collected from a calibrated Simrad EK60 echo sounder system with transducers mounted in the vessel hull and running 4 frequencies (18, 38, 120 and 200 kHz). Pelagic trawl hauls were carried out close to the surface using the Multpelt 832 trawl and a trawling speed of ca. 4 knots, which usually has an opening width of 65 m and height of 35 m. On a few occasions deeper hauls were carried out. Data were also collected using the Simrad SH 80 multibeam sonar mounted on board. The sonar was fixed at 600 m range, 90 degrees bearing and -4 degrees tilt.

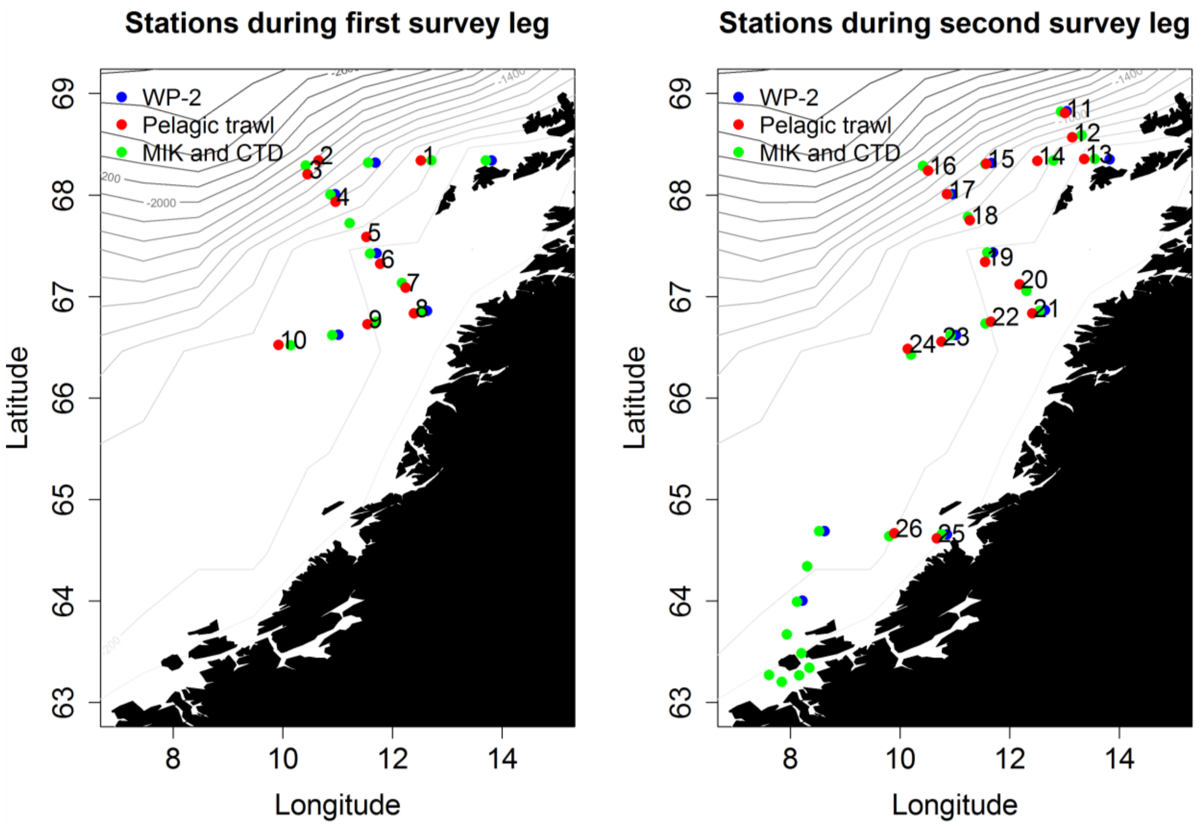


Figure 1. Stations with stations numbers carried out during the first part (30.05-03.06; left) and second part (03.06-08.06; right) of the survey. Direction of both transects was north-south. Note that only pelagic trawl stations are accompanied by a station number.

Data processing

Herring larvae were sorted out from the sample and counted. Max 50 herring were measured and staged from each station. In addition, max 50 herring larvae were preserved in alcohol in a bulk.

All biological data were sampled and recorded according to standardized procedures described by Mjanger et al. (2007). From the pelagic trawl, samples of 10 fish were obtained from all pelagic fish in the catch and measured for length, weight, gonad weight and maturity state and age. Stomachs of 10 fish of each species were cut out and immediately stored in the freezer. During processing, the stomach contents were carefully taken apart and all identifiable prey identified to the lowest possible taxonomic group. Identifiable prey items were counted. *C. finmarchicus* copepodite stage (CI-VI) was determined, and total length to the nearest 0.1 mm was recorded for other identifiable predetermined prey organisms. Prey species and groups from each stomach were oven-dried separately at 60°C for more than 24 h to constant dry weight and weighed to nearest 1 mg.

In addition, stomachs from another 40 fish were weighed and cut open for investigation under the binoculars during the survey. Stomach content in volume percentage was then categorized into main prey groups. These results are not presented here, but showed consistency with the laboratory results.

Results and discussion

Distribution and abundance of mackerel

Mackerel were caught in nearly all trawl hauls, also the northernmost, and occasionally in high numbers (Figure 2). The acoustic recordings, including the sonar recordings, showed little mackerel, suggesting that mackerel were distributed in thin aggregations close to the surface, which was confirmed by the fishermen in the area waiting for the mackerel to aggregate to allow for efficient harvesting. Even though mackerel were caught in nearly all hauls, the variation in catch rates between stations was substantial (Figure 2). A very rough estimate of mackerel abundance using the average catch per unit distance was made for the entire surveyed area. The estimate is made under the assumption that the pelagic trawl catches mackerel representatively and that mackerel is distributed close to the surface available to the trawl. It showed a total amount of 50000 and 55000 tons for the first and second coverage, respectively. It should be noted that acoustic recordings interpreted as mackerel were made in deeper waters (150-200 m) at the shelf edge outside the distribution depth range of herring larvae. The interpretation from the acoustics was confirmed by one deep trawl sample.

During the regular monitoring survey a month prior to the present investigation mackerel was only recorded south of 66° N and mainly off the shelf edge (Figure 2; upper).

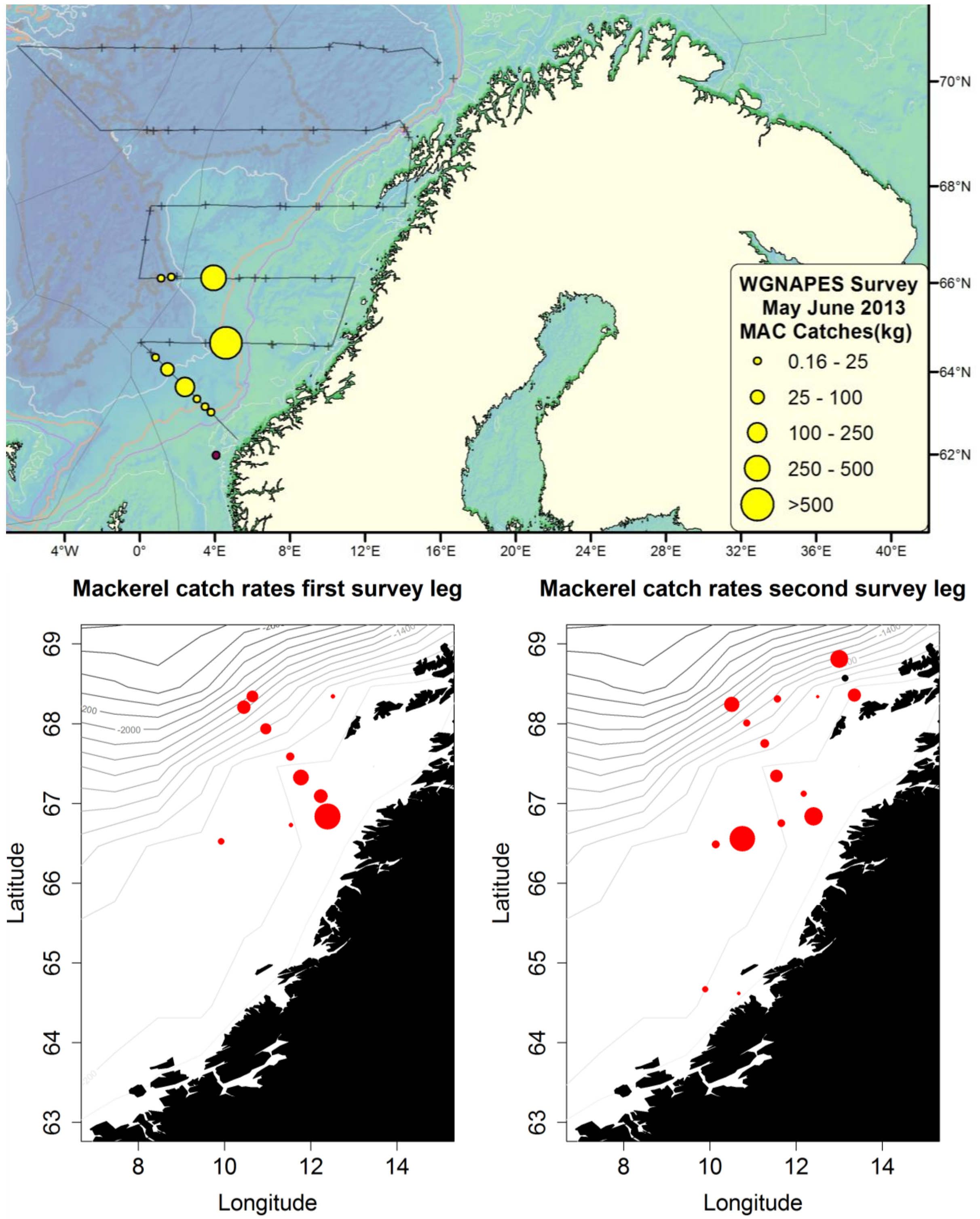


Figure 2. Mackerel catch rates from the regular monitoring survey (upper), and the first (bottom left) and second (bottom right) coverage. The mackerel catches during the ecosystem survey were done between 4 and 10 May. The catch rates are calculated as catch weight per nautical mile hauled. The size of the circle in the bottom figures is proportional to the fourth root of the catch rate, with max size corresponding to a catch of ca. 2.3 tons per nautical mile hauled. Black dot denotes zero catch.

Distribution and abundance of herring larvae

Herring larvae were obtained in all MIK hauls, but the numbers varied from 0.03 to 17.6 larvae pr minute hauled (Figure 3). When interpolating the observed larval density over the entire surveyed area, an estimated abundance of 2.4 larvae pr m^2 surface ($4.9 \cdot 10^{10}$ larvae) during the first coverage had decreased to 0.8 ($1.8 \cdot 10^{10}$ larvae) during the second. The decrease was particularly clear in the north. Current speed along the Norwegian coast generally spans from 10-50 cm sec^{-1} and taking into account delays in larvae drift due to eddies and topographic features, net northwards drift speed of larvae is approximately 10 km day^{-1}. This suggests that much of the larvae in the north had drifted out of the area between the first and second survey leg.

Larvae abundance was generally lower in the south than in the north, and when comparing with the larvae abundance from the regular monitoring survey almost a month earlier, the abundance in the south was radically lower by the time of the present study.
The abundance of herring larvae was in general higher close to the coast in the covered area than further off the coast (Figure 3).

Distribution and abundance of zooplankton

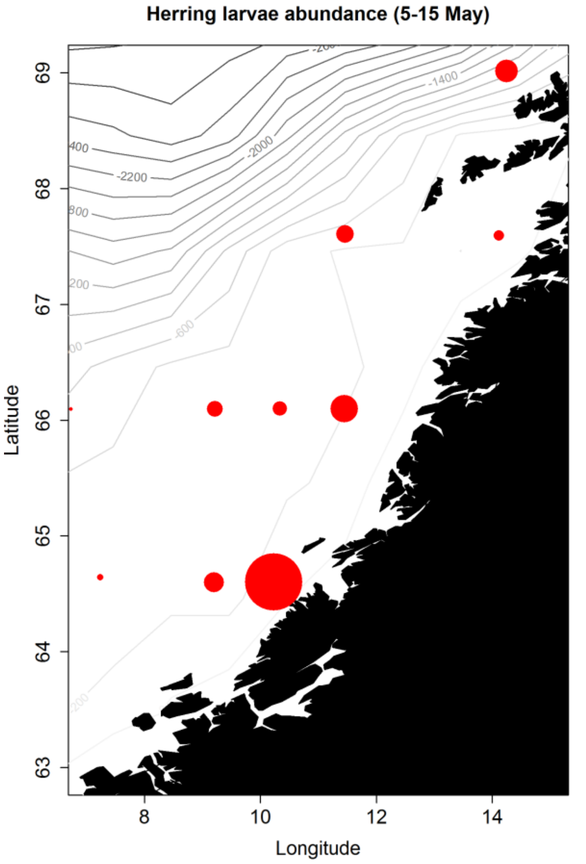
The total amount of zooplankton estimated from the WP2 net hauls was variable among the stations (Figure 4), but the overall mean did not change between first and second survey leg. Although the species composition of the plankton samples have not been determined for the present study, the size composition of the samples suggests that the copepod *C. finmarchicus* most likely made up the bulk of the biomass (Wiborg 1955; Marshall & Orr 1972; Aksnes & Blindheim 1996; Hirche et al. 2001).

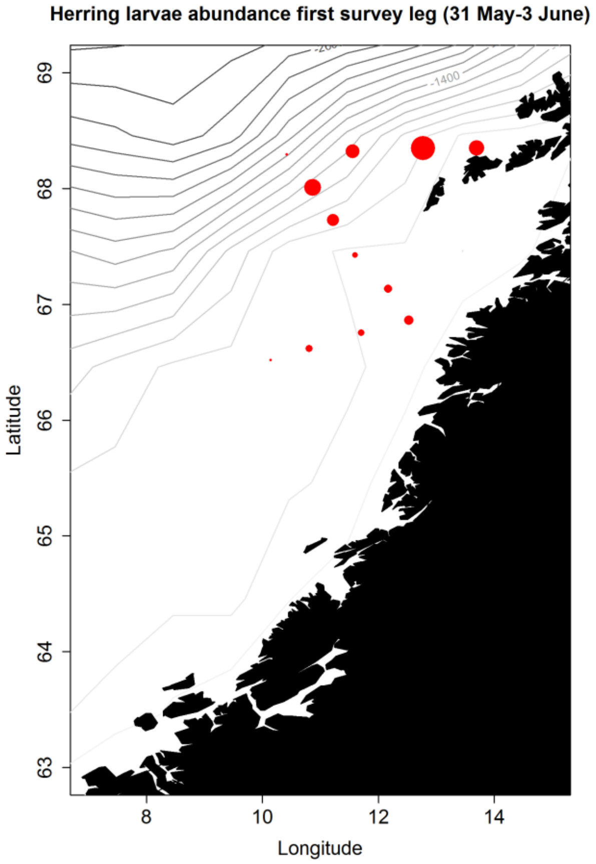
Mackerel feeding

Overall prey consumption

Calanoids dominated the diet of mackerel. 97% of the non-empty mackerel guts contained calanoids. 68% of the total consumption during the first survey leg and 78 % during the second leg was calanoids (Figure 5; upper). *C. finmarchicus* dominated the calanoid group. 91% of the mackerel guts with certainty contained *C. finmarchicus,* and mean prey weight of what could with certainty be allocated to *C. finmarchicus* was 188 mg dry weight or 31 % of the total consumption. A large part of the calanoids that were partly digested and could not be allocated to species, was likely *C. finmarchicus*.

Of all the mackerel guts sampled, 45% contained prey recognizable as herring larvae (108 out of 238), and the proportion of larvae out of total prey consumption was 23% during first survey leg and 6.5% during second leg (Figure 5; upper). The decrease in larvae consumption to 1/3 from the first to the second survey leg corresponds in magnitude with the decrease in estimated larvae abundance. The maximum count in one single gut was 225 larvae, and out of the 38 guts in which larvae could be counted, 19 contained 5 or more individual larvae while 12 contained a single larvae. Altogether 618 larvae were counted in the guts, but in many cases the digestion had come too far to allow for counting. Krill, amphipods and other prey groups were less important in the diets.





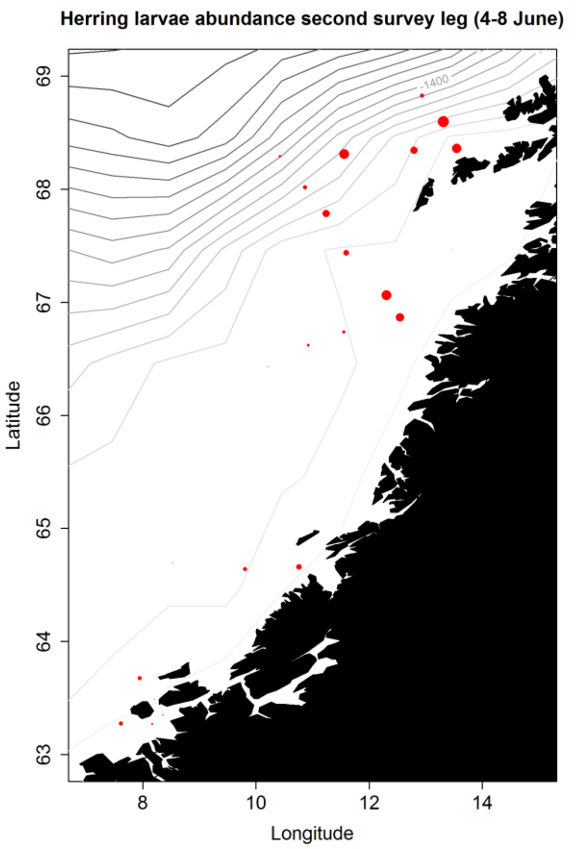


Figure 3. Index of larvae abundance from the regular monitoring survey (left), first coverage (middle) and second coverage (right). The index refers to number of larvae per minute hauled and the size of a point is proportional to the square root of the index with max size corresponding to ca. 18 larvae per minute (total of 600 larvae in the net).

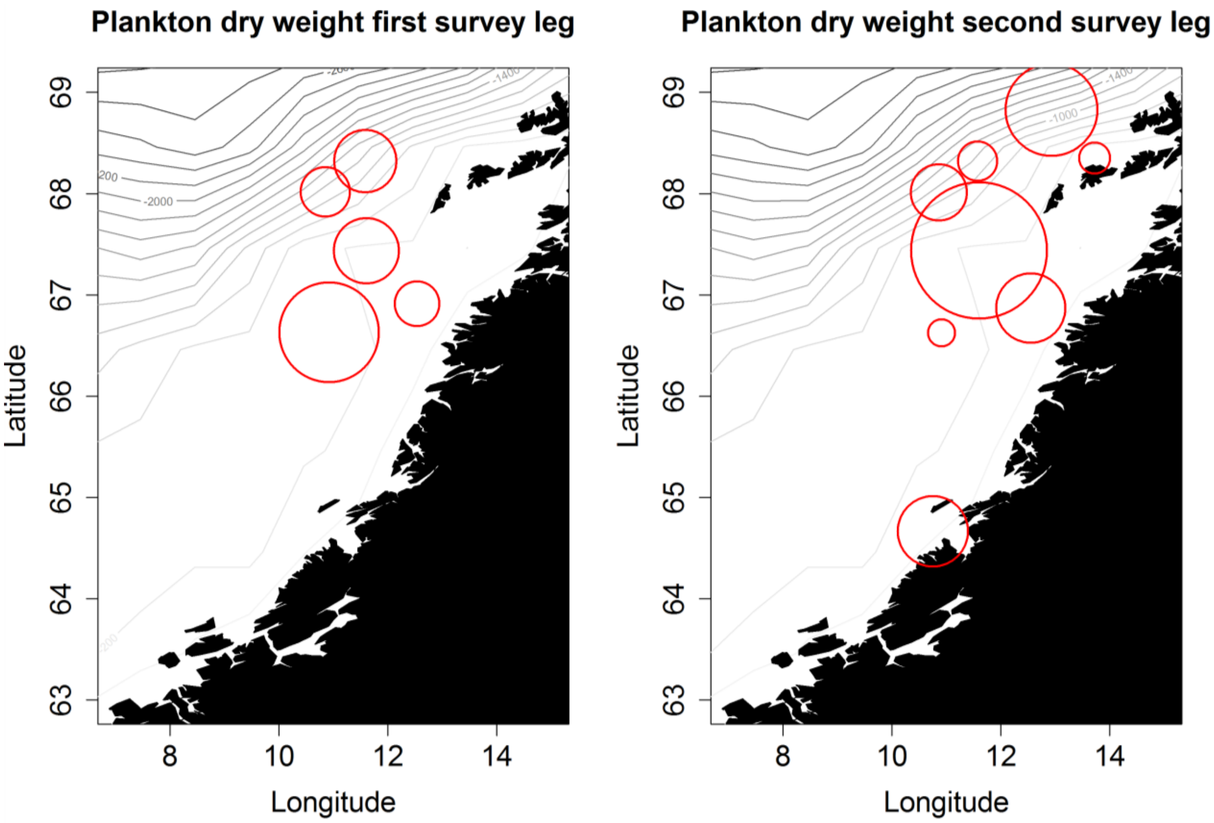


Figure 4. Total amount of plankton (dry weight) estimated from WP2 net hauls. Size of the circle is propor-tional to measured dry weight. Max size corresponds to about 16 g m^{-2}.

There was a considerable variation in both diet composition and amount consumed between individual mackerel (See Figure 5 middle), and also high variability from station to station (Fig. 5; lower). The mean weight of prey in a gut varied by more than an order of magnitude between the lowest and highest station from <100 mg to >1500 mg dry weight.

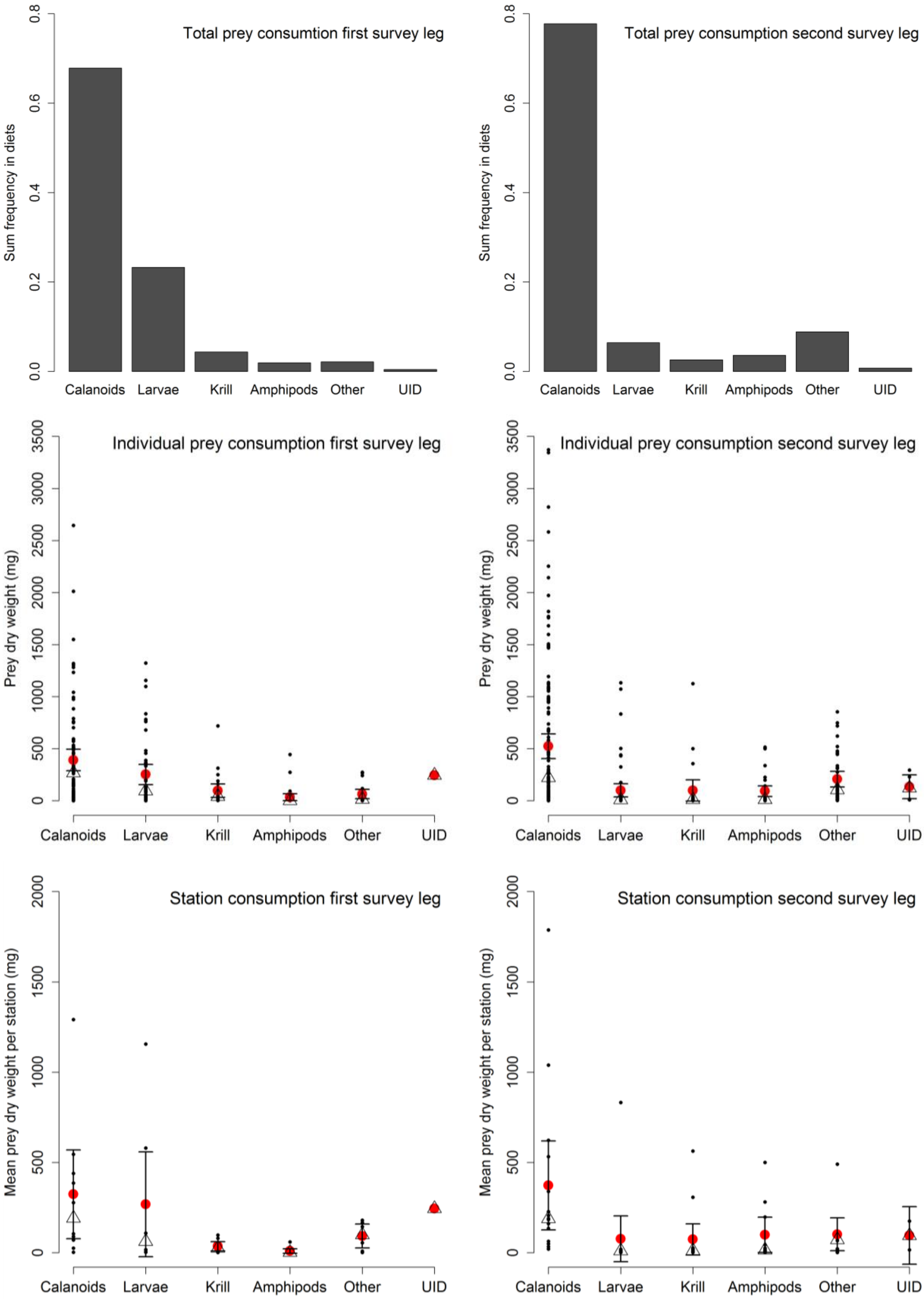


Figure 5. Total consumed prey allocated to main prey groups (upper), prey consumption by individual mackerel (middle) and mean consumption by station (lower). 'Larvae' denotes herring larvae and 'UID' unidentified prey items. Black dots denote prey weight for individual mackerel (Max 10 per station), red dots mark means, triangles mark median values, and bars mark standard error. Note that cases of zero consumption are not included in the calculation of the mean values.

Consumption of herring larvae

Herring larvae consumption by mackerel varied considerably between stations. In a few stations, no guts contained larvae whereas in stations 1 and 14, guts contained on average more than 500 mg dry weight of herring larvae (Figure 6). Also feeding incidence was variable between stations (Figure 7), but feeding incidence was in several cases high even though the amount of larvae consumed was low.

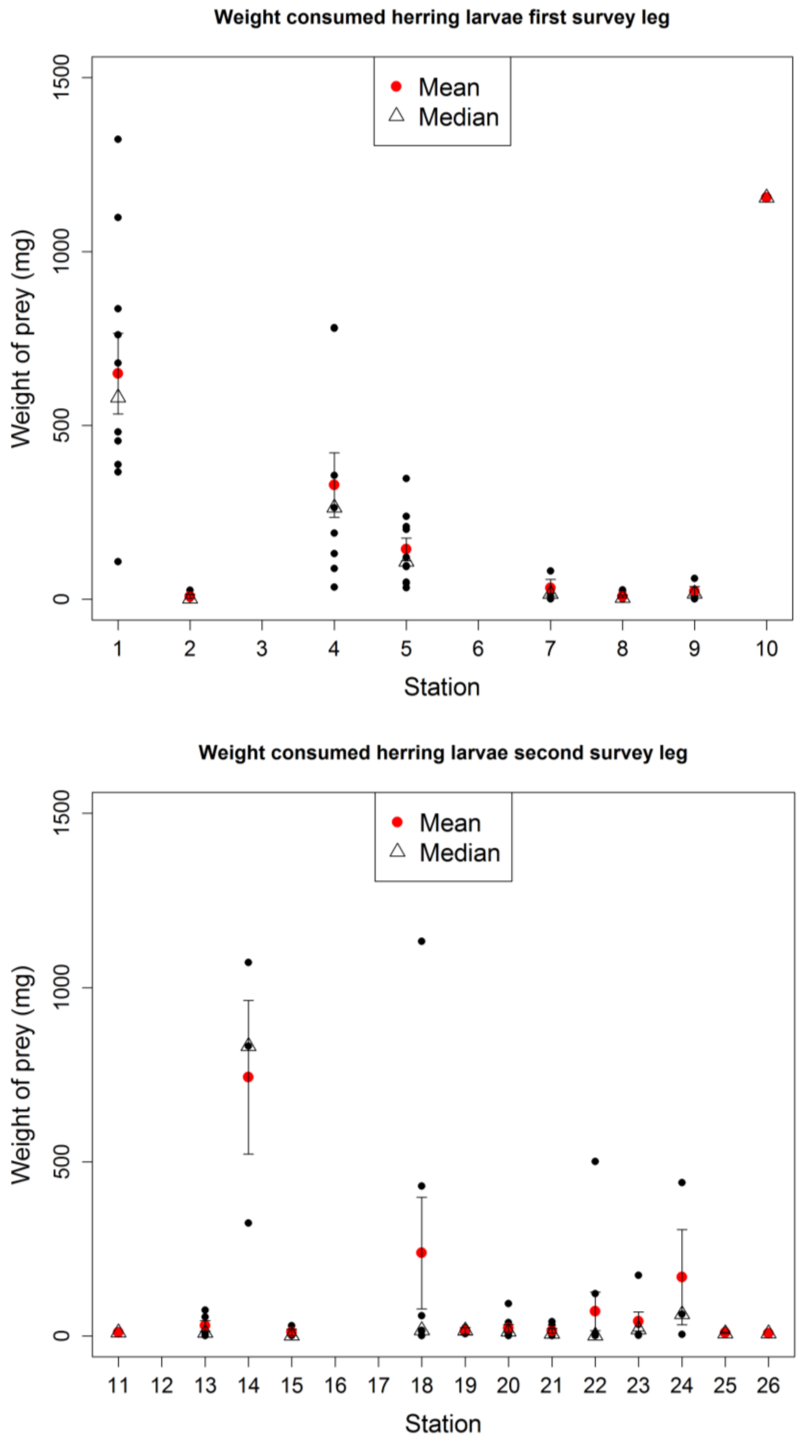


Figure 6. Weight of consumed herring larvae in mackerel guts by station. Black dots denote prey weight for individual mackerel (Max 10 per station), red dots mark means, triangles mark median values, and bars mark standard error. Note that cases of zero consumption are not included in the calculation of the mean values.

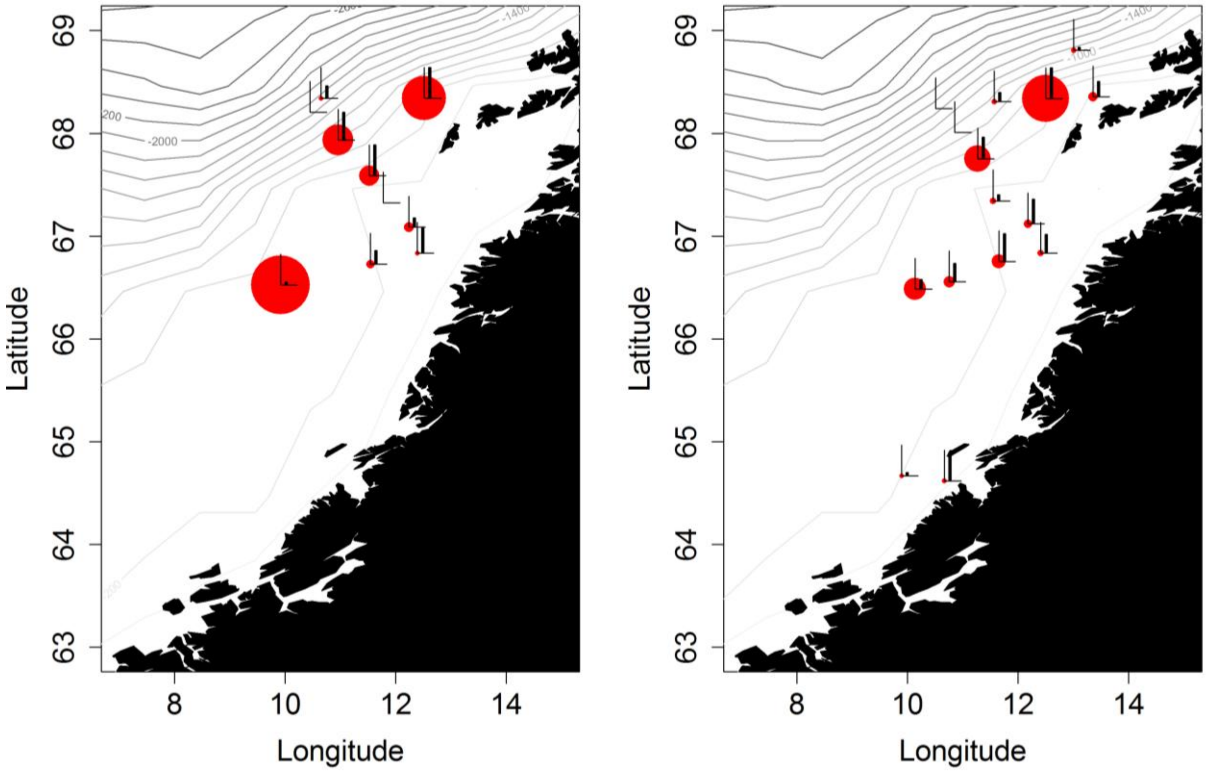


Figure 7. Feeding incidence and amount of larvae in mackerel guts. The vertical bars denote the proportion of mackerel stomachs containing herring larvae, where a proportion of 100 % is indicated by equal height of bar and y-axis line. The size of the red circle is proportional to the square root of the total weight of herring larvae in the guts and shows mean weight per station (only guts containing larvae included). 10 mackerel were investigated for each station.

In one coastal station taken close to Finnmark on 25 July during a separate survey the same year (2013), 9 of 10 mackerel had consumed herring which had now metamorphised. Consumption ranged from 1-21 (mean ~ 8) individual herring. This result shows that herring consumption by mackerel also occurs during summer in the Barents Sea, but the importance of this on a larger scale is not known and should be studied further.

Relationship between mackerel feeding and herring larvae abundance

There were indications of a relationship between the amount of consumed larvae in the guts and the estimated amount of larvae (Figure 8) and also between proportion of mackerel with larvae in the guts and estimated amount of larvae. They indicate that both a higher proportion of the mackerel feed on larvae when larvae abundance is high, and that the consumption rate of larvae is higher. On the other hand, there was no relationship between estimated mackerel abundance and estimated amount of larvae which suggests that mackerel do not follow the larvae concentrations on a regional scale, but rather feed opportunistically on larvae when there is overlap.

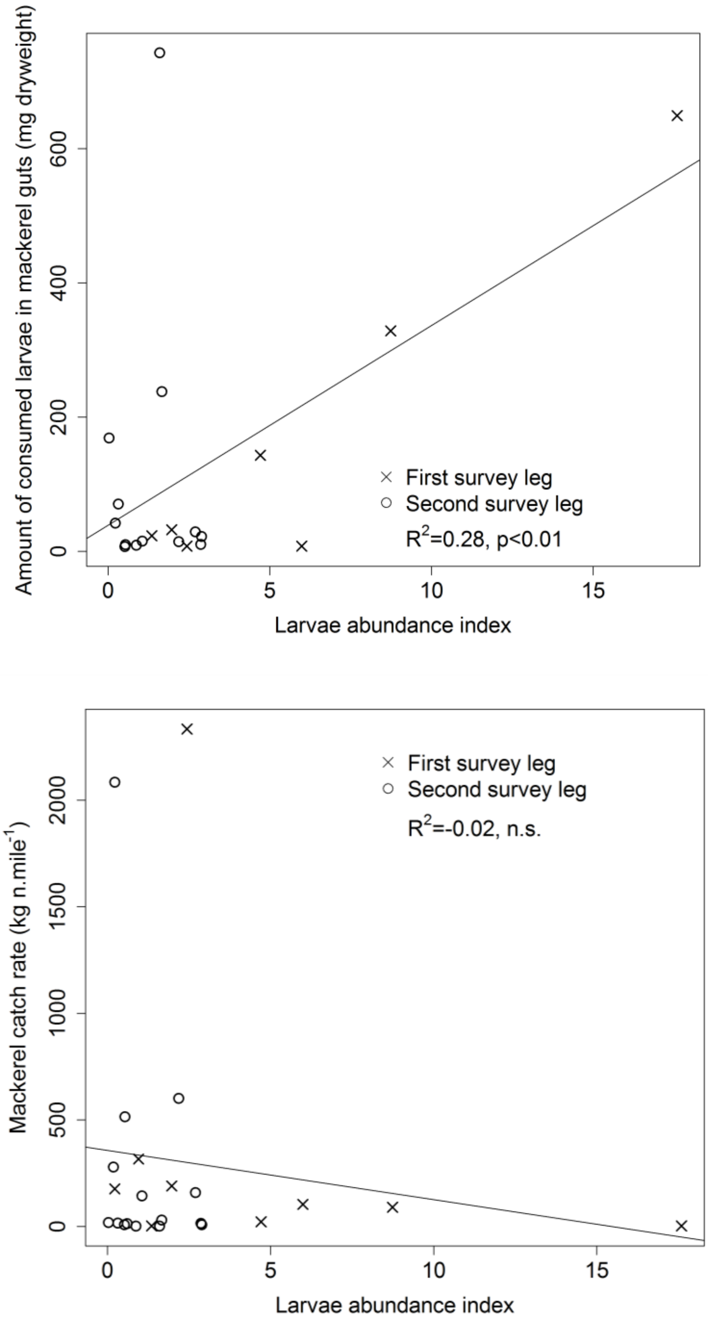


Figure 8. Average amount of larvae in mackerel guts (left) and mackerel catch rate (right) as function of estimated larval abundance. 'n.s.' denotes not significant.

Mackerel consumption of herring larvae on large scale

Theoretically, mackerel is capable of consuming huge quantities of herring larvae, but in practice there are several limiting factors.

Mackerel are active animals and need a substantial energy intake to maintain basic metabolism and a high activity level including long migration. Utne et al. (2012) estimated a daily required food intake of between 2.5 and 4.5 % of the body weight, depending on the quality of the food and the time of the season. Herring larvae are high energy food and our study was carried out early in the feeding season, so a consumption rate in the lower part of the estimated consumption range in Utne et al. (2012) seems reasonable. If the index from the herring larvae cruise in April 2013 is interpreted as absolute abundance, it provides a total abundance estimate of herring larvae at 71.6 trillion larvae ($7.16 \cdot 10^{13}$). Assuming a daily larval mortality rate of 10 % (Christensen, 1985), the total abundance of larvae during the time of our survey, around 50 days later, would be around 369 billion ($3.69 \cdot 10^{11}$) larvae. We estimated the weight of a single larvae from the undigested larvae in the mackerel guts to 8.4±1.9(SD) mg dry weight (N=80) or 52.6±12.1(SD) mg wet weight. In biomass, the larvae were thus estimated to constitute 19400 tons at the time of our survey. Assuming that herring larvae constitutes 23 % of the mackerel diet like was found during the first leg of the present study, and given the same amount of overlap between mackerel and herring larvae, it would have taken 3.4 million tons of mackerel to prey the estimated total amount of larvae down in one day. In our case, the estimated 50000 tons of mackerel in the area would be capable of preying down the 49 billion larvae estimated to be present in our survey area in around 9 days.

We underline that the estimates presented above are associated with a substantial degree of uncertainty and all could have been subject to separate studies. Attempts to estimate these uncertainties have not been made here, but the large scale projections are illustrative of feeding efficiency and potential impact. One should also be aware that the present study only focused on mackerel consumption of herring larvae, and that larval consumption by other predators like saithe was observed, but not quantified here.

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