Scottish Marine and Freshwater Science

The Scottish Government

SCOTTISH MARINE AND FRESHWATER SCIENCE VOLUME 3 NUMBER 4

The Distribution of Zooplankton Prey of Forage Fish in the Firth of Forth Area, East Coast of Scotland

G Gomez Garcia, D Demain, H Drewery and A Gallego

marinescotland science

ISSN : 2043 - 7722

Scottish Marine and Freshwater Science Report
Vol 3 No 4

The Distribution of Zooplankton Prey Of Forage Fish in The Firth of Forth Area, East Coast of Scotland

Guillermo Gómez García, Dorota Demain, Helen Drewery and Alejandro Gallego

The Scottish Government, Edinburgh 2012

Marine Scotland is the directorate of the Scottish Government responsible for the integrated management of Scotland's seas. Marine Scotland Science (formerly Fisheries Research Services) provides expert scientific and technical advice on marine and fisheries issues. Scottish Marine and Freshwater Science is a series of reports that publish results of research and monitoring carried out by Marine Scotland Science. These reports are not subject to formal external peer-review.

This document is available from our website at **www.scotland.gov.uk**.

ISBN: 978-1-78256-005-0 (web only)

ISSN: 2043-7722

The Scottish Government
St Andrew's House
Edinburgh
EH1 3DG

Produced for the Scottish Government by APS Group Scotland
DPPAS13279 (08/12)

Published by the Scottish Government, August 2012

THE DISTRIBUTION OF ZOOPLANKTON PREY OF FORAGE FISH IN THE FIRTH OF FORTH AREA, EAST COAST OF SCOTLAND

Guillermo Gómez García[1,3], Dorota Demain[2,3], Helen Drewery[3] and Alejandro Gallego[3]

[1]University of La Laguna, Biology Faculty, Astrofísico Francisco Sánchez,S/N. 38206 Campus Anchieta, Tenerife, Canary Islands, Spain

[2]BMT Cordah Limited, Scotstown Road, Bridge of Don, Aberdeen, AB23 8HG, Scotland

[3]Marine Scotland Science, 375 Victoria Road, Aberdeen, AB11 9DB, Scotland

Abstract

Forage fish are an important link between lower (zooplankton) and higher (carnivorous fish, birds and mammals) trophic levels. Despite a closure of the industrial fishery for forage fish in the Firth of Forth area, off the Scottish east coast, since 2000, recruitment has been variable. As part of a study investigating forage fish population dynamics and recruitment variability, the distribution of zooplankton in the area was studied in June 2010. The presence of the most abundant zooplankton species and those most prevalent in the stomachs of forage fish were presented, and compared to the distribution of those fish species. The results showed species- and size-specific selective feeding by forage fish, and both overlaps and differences between the distribution of those fish and their zooplankton prey.

Introduction

The abundance of zooplankton is very important to other trophic levels (e.g. planktivorous forage fish such as sandeel *(Ammodytes marinus)*, herring *(Clupea harengus)* and sprat *(Sprattus sprattus),* including top predators. In this study, zooplankton samples were analyzed to characterise the prey field of forage fish. The composition of the zooplankton community and their abundance are important to assess if there is enough suitable food for these organisms in the study area.

The area of Wee Bankie in the Firth of Forth (Scottish east coast, Figure 1) has been closed to the sandeel industrial fishery since 2000, initially due to the low sandeel numbers (Greenstreet *et al.,* 2010) and the notion that the fishery was solely driving these reductions and consequently top predators were being adversely affected (Furness and Camphuysen, 1997). After the closure, sandeel biomass went up at first (Daunt *et al.,* 2008) but recruitment and stock numbers have been variable. The reason for this is largely unknown because we do not understand fully the ecosystem-level interactions. A key component in our understanding of the system is the knowledge of the abundance and distribution of zooplankton species within the area.

These forage fish (sandeel, herring and sprat) are important because they are the food of many top predators like seabirds (Furness, 2003), and their abundance is important for maintaining these seabird populations (mainly black-legged kittiwake (*Rissa tridactyla*) and common guillemot (*Uria aalge*)) stable.

The Firth of Forth is an estuary off the east coast of Scotland between the cities of Edinburgh and Dundee. This area is of special ecological interest because there are important communities of seabirds (kittiwakes and guillemots) which feed on forage fish populations in the area, particularly the sandeel that inhabit the sandy shallow banks on the northern edges of the Firth of Forth (see bathymetry on Figure 2).

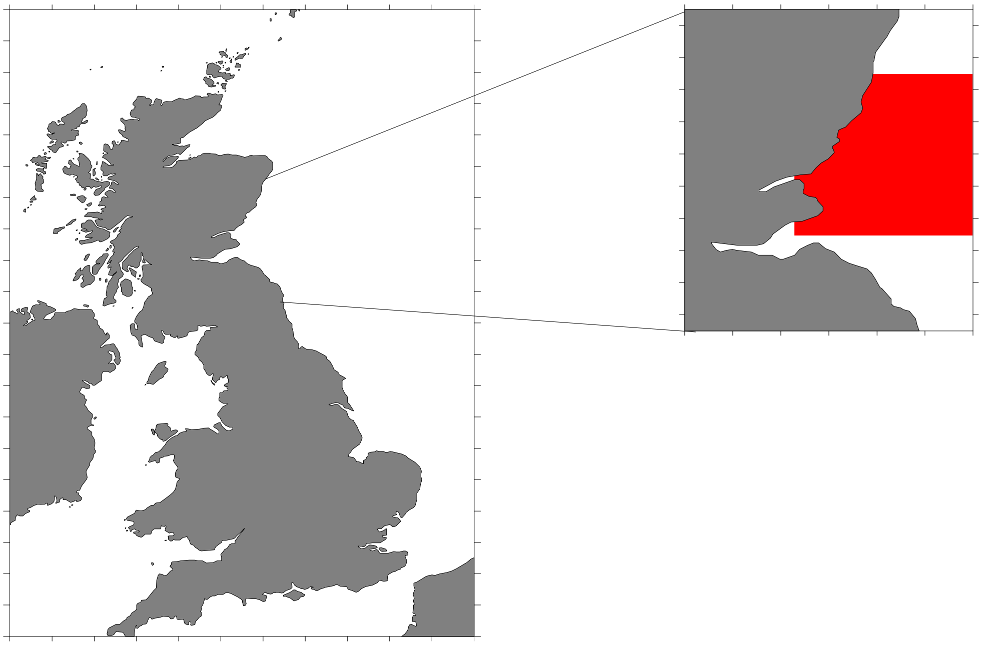

Figure 1: The study area (marked in red) located in the Firth of Forth in the east coast of Scotland (United Kingdom).

Materials and Methods

Field Work

The zooplankton samples were collected in the Firth of Forth area between 2 and 22 June 2010, on MRV *Alba na Mara* (cruise 0710A). Samples were collected using a 40 cm diameter Bongo net with a mesh size of 95 µm (cod end 200 µm) over a grid of stations (Figure 2a). The sampler was deployed on a vertical tow from near the bottom to the surface at each station and the zooplankton samples were preserved in 4% borax buffered formaldehyde.

The latitude and longitude limits of the study area were 56˚58,06'N - 56˚03,09'N and 2˚40,179'W - 1˚19,98'W, respectively.

Demersal fishing for forage fish (sandeel, sprat and herring) was carried out at 19 sites (Figure 2b). Their distribution over the study area was investigated, and their stomach contents were analysed to compare their diet with the distribution of zooplankton in the area.

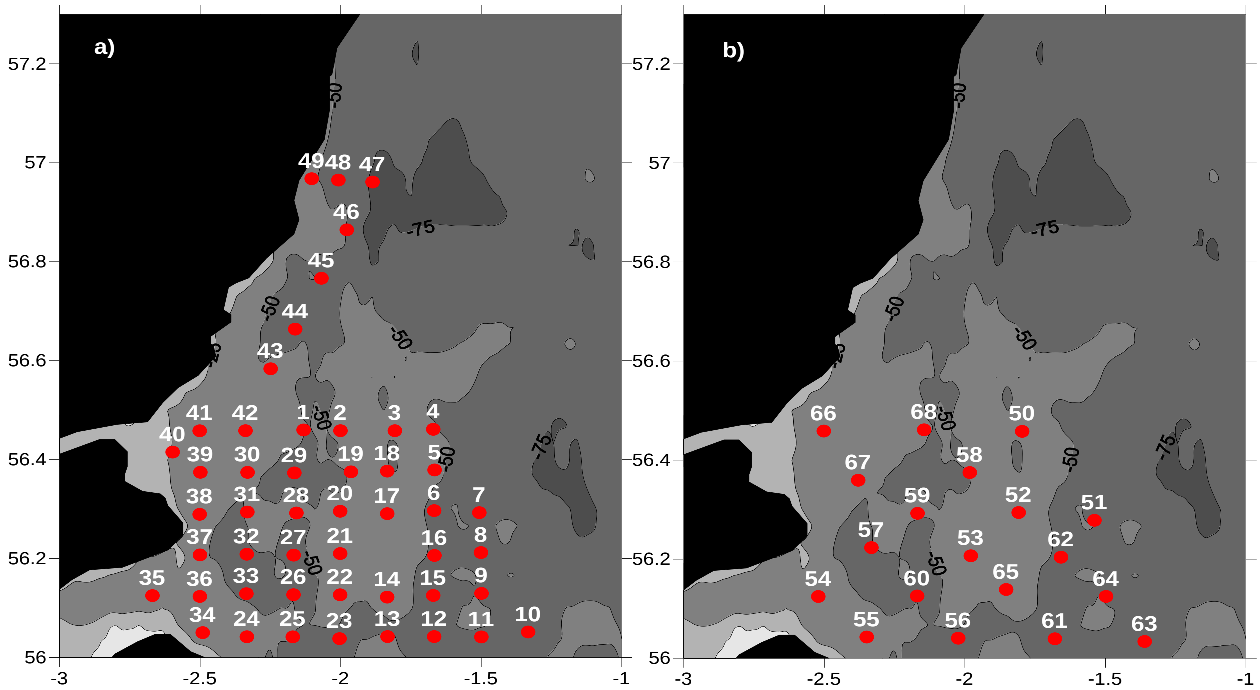

Figure 2: Bathymetric map of the study area with red dots indicating the position of a) zooplankton stations and b) demersal fishing stations.

Laboratory Analyses

Organisms from each sample bottle were collected from a filter (50 µm). All specimens collected on the filter were placed in a large dish and larger species (such as *Calanus* sp., *Sagitta* sp., fish larvae, decapod larvae, euphausids, mysids, etc.) were picked out.

Calanus spp. analysis

A maximum of 20 *Calanus* CV (copepodid stage V), 20 CVI Female and 20 CVI Male were taken from the sample to obtain the *Calanus finmarchicus*: *Calanus helgolandicus* ratio for the whole sample. If there were fewer than 100 CV and CVI, these individuals would be returned to the sample after the ratio was established.

Fish eggs

In the case of fish eggs, only their presence or absence in the zooplankton samples was noted.

Sub-sampling

Depending on the number of specimens in the sample, a number of subsamples (up to three) were taken from each sample, counting all animals in each subsample. Then the counts were raised by the appropriate dilution factor to obtain the total number of animals in the whole sample.

The following formula was used to calculate an estimate of abundance (number of organisms m^{-2}) of the different species (and developmental stages in the case of some species) in each sample:

Species abundance = $(N/(\pi * r^2 * d * 0.7)) * dbottom$

N: Number (count) of organisms of each species in each sample
d: Maximum sampler depth (m)
dbottom: Bottom depth (m)
r: Radius of Bongo net

Data Analysis

Zooplankton abundance data in the study area were estimated in Microsoft Excel and gridded by station using the Surfer software package (Golden Software, Inc., California). The six most abundant species in the zooplankton samples in the study area (see Results section) were then represented. Abundance data were resolved at each station by krigging and were subsequently displayed as gridded data. The same process was applied to a number of less abundant zooplankton species in the study area which constituted in excess of 5% in the diet of the fishes sampled. A similar approach was carried out to display the total zooplankton abundance over the study area.

Forage fish abundance data (for herring, sprat and sandeel) in the study area were also displayed as abundance maps.

Results

Species Recorded

The list of species/stages found in the water column in the study is presented in Table 1. The most abundant taxa (stage, species or taxonomic group, depending on the level of analysis) were *Evadne nordmanni*, *Acartia clausii* CV-CVI, *A. clausii* CIII-CIV, calanoid nauplius, *Temora longicornis* CV-CVI and *Oithona* spp. CI-VI. Their distribution over the study area will be presented below. The distribution of other taxa abundant in the diet of forage fish (>5%; see Stomach Analysis section) will also be mapped below. These were Appendicularia, *T. longicornis* CIII-CIV, cyprid, *Centropages hamatus* CV-CVI and decapods.

Table 1

List of all species, taxa and developmental stages found in the zooplankton samples.

Euphysa aurata	*Calanus helgolandicus* CV-CVI	*Oithona* spp. CI-VI
Aglantha digitalis	*Paracalanus parvus* CV-CVI	*Oithona* spp. NI-VI
Coelenterata	*Paracalanus parvus* CIII-CIV	*Oithona* spp. Eggsac
Steenstrupia spp.	*Pseudocalanus elongatus* CV-CVI	Mysidae
Leuckartiara octona	*Pseudocalanus elongatus* CI-CII	Isopoda
Phialidium spp.	*Pseudocalanus elongatus* CIII-CIV	Amphipoda
Mitrocomella polydiademata	*Microcalanus pusillus* CV-CVI	*Parathemisto* spp.
Podocoryne borealis	*Temora longicornis* CV-CVI	*Hyperia* spp.
Cyanea lamarckii	*Temora longicornis* CI-CII	Euphausiidae FURCILIA
Bouganvillia britannica	*Temora longicornis* CIII-CIV	*Limacina retroversa*
Obelia spp.	*Metridia lucens* CI-CII	Decapoda (Larvae)
Lamellaria spp.	*Metridia lucens* CIII-CIV	Lamellibranch (Larvae)
Aurelia spp.	*Metridia lucens* CV-CVI	Gastropoda (Larvae)
Lizzia blondina	*Centropages hamatus* CV-CVI	Polychaeta (Larvae)
Pleurobracchia spp.	*Centropages hamatus* CI-CII	Cyphonautus (Larvae)
Bolinopsis infundibulum	*Centropages hamatus* CIII-CIV	Echinoidea (Larvae)
Unknown Jellyfish	*Centropages typicus* CV-CVI	*Parasagitta* spp. Juvenile
Podon leuckartii	*Anomalocera patersoni* CV-CVI	*Parasagitta elegans*
Evadne nordmanni	*Acartia clausii* CV-CVI	Fish (Eggs)
Cyprid	*Acartia clausii* CI-CII	Fish (Larvae)
Cirriped nauplii	*Acartia clausii* CIII-CIV	Clupeidae
Calanoid nauplius NI-VI	Harpacticoid spp. CI-VI	Ammodytidae (Larvae)
Calanus spp. CI-CII	Harpacticoid spp. NI-VI	Gadiformes (Larvae)
Calanus spp. CIII-CIV	*Microsetella norvegica* CI-VI	Polychaeta (Adult)
Calanus finmarchicus CV-CVI	Oncaeid spp. CI-VI	*Tomopteris* spp.
Appendicularia spp.	*Caligus* spp.	Ophiura juvenile
Invertebrate (Eggs)	Sea star	Megalopa
Cephalopoda	Ascidiacea (Larvae)	Parasitic copepod
Phoronida	Nephrops	*Caligus* copepodite I-VI
Lamellaria perspicua	*Cerianthus* spp.	

Species Distribution

In this section the six most abundant species in the study area are presented, as well as other taxa abundant in the diet of forage fish (>5%; see stomachs analysis section). These abundant species in the stomachs were Appendicularia, *T. longicornis* CIII-CIV, cyprid, *Centropages hamatus* CV-CVI and decapods. They are also mapped below.

Several stations in the study area exhibited high levels of total zooplankton abundance (station number 1, 28, 29, 30, 42 and 44; Figure 3). In order of importance, the most abundant species in the study area was *E. nordmanni* (Figure 4). Its highest abundance was observed in the centre of the study area, decreasing towards the western and eastern boundaries of the area. Of the copepod species, *A. clausii* (Figure 5 and 6) and *Oithona* spp. (Figure 9) were the most abundant (*A. clausii* CV-CVI being the most abundant). The distribution of *A. clausii* CV-CVI was similar to that of *E. nordmanni*, but there was one station further into the Firth of Forth with high density. In the case of *Oithona* spp., their distribution was largely comparable to that of *E. nordmanni*, with a high density in the centre of the study area, decreasing towards the boundaries. Other abundant organisms were *A. clausii* CIII-CIV, with a similar distribution to *A. clausii* CV-CVI, but with lower densities (Figure 6). Calanoid nauplii, displayed a more or less regular distribution in the study area (Figure 7). *T. longicornis* CV-CVI, presented the highest densities offshore and a low density elsewhere (Figure 8), Appendicularia had an irregular distribution, most abundant in station 17 (Figure 10). *T. longicornis* CIII-CIV, were irregularly distributed, with stations with a high density in the centre of the study area, inshore and offshore (Figure 11). Cyprids were also irregularly distributed, with their highest densities inshore (Figure 12). *C. hamatus* CV-CVI, were irregularly distributed, with an offshore abundance maximum (Figure 13). Finally, decapods, were very irregularly distributed over the study area, with their highest density in the inshore station 43 (Figure 14). Fish eggs were widespread in the study area and were just absent from 8 stations. Their distribution is shown in Figure 15.

The zooplankton species composition in the different stations varied through the study area. The high contribution of *E. nordmanni* and stages CV-CVI of *A. clausii* can be seen in Fig. 16.

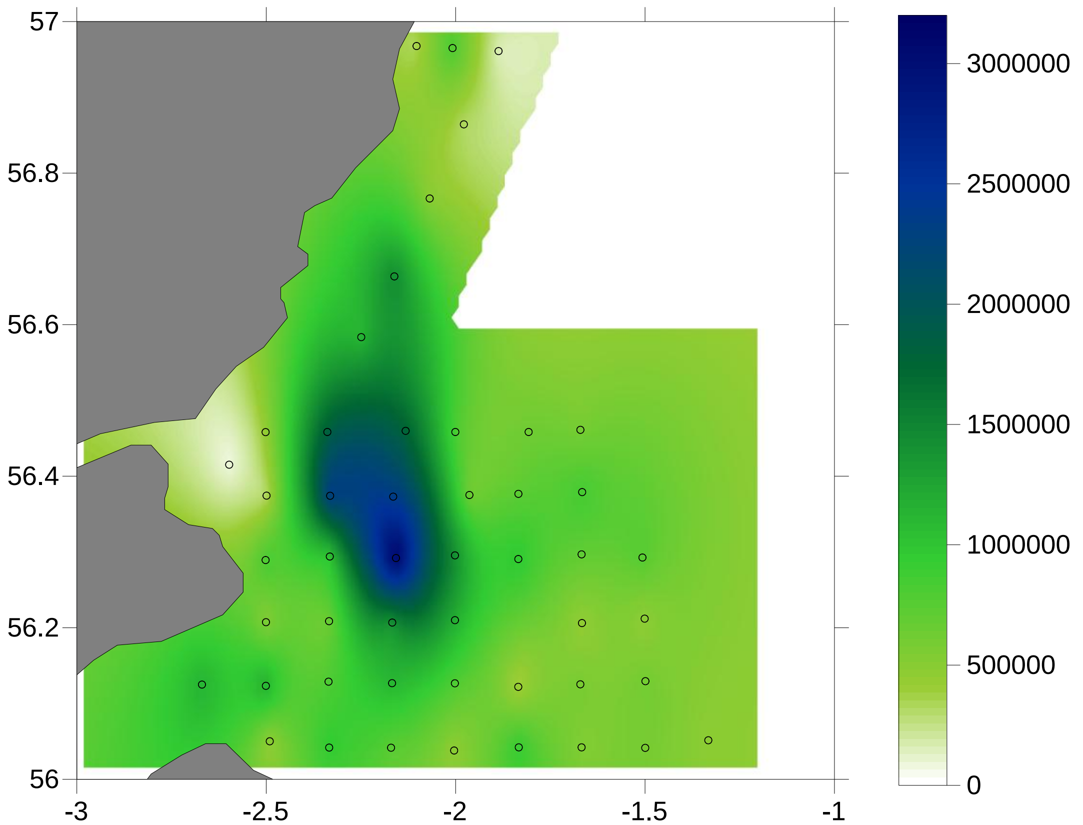

Figure 3: Map of the distribution of the total zooplankton abundance in the study area in number of organisms m^{-2}.

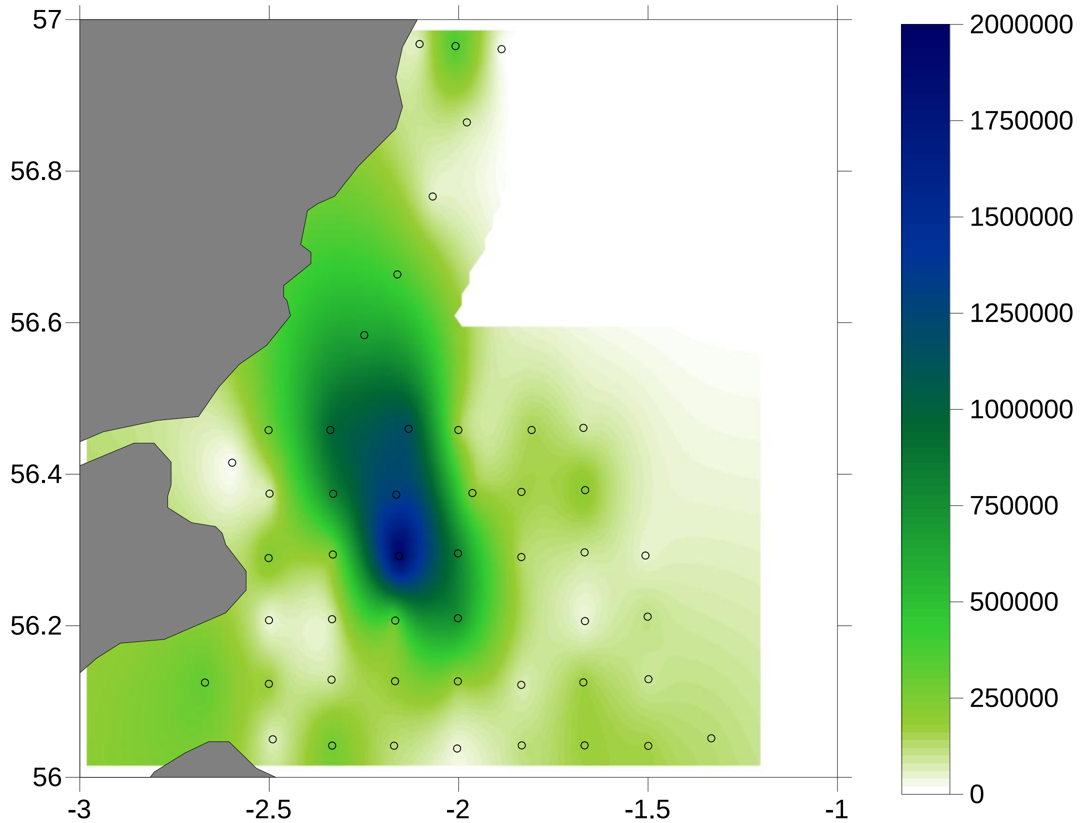

Figure 4: Map of the distribution of *E. nordmanni* abundance in the study area in number of organisms m^{-2}. Note a different scale to that of subsequent Figures.

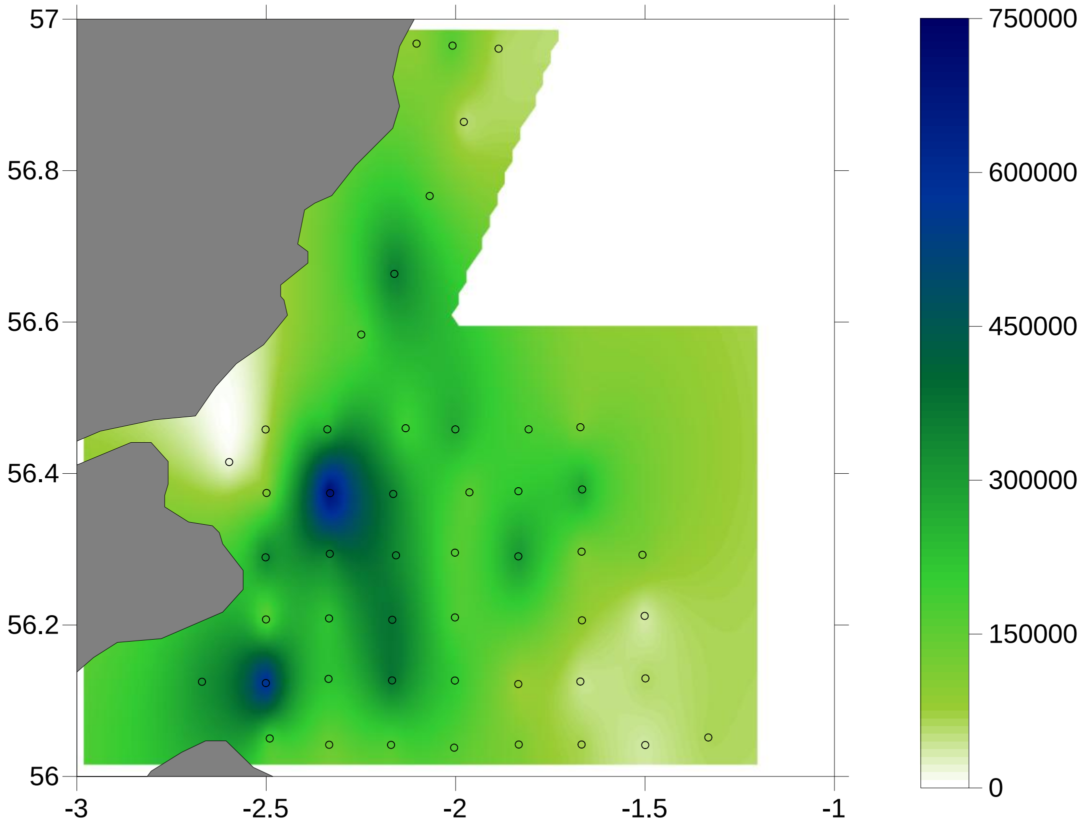

Figure 5: Map of the distribution of *A. clausii* stages CV-CVI abundance in the study area in number of organisms m^{-2}.

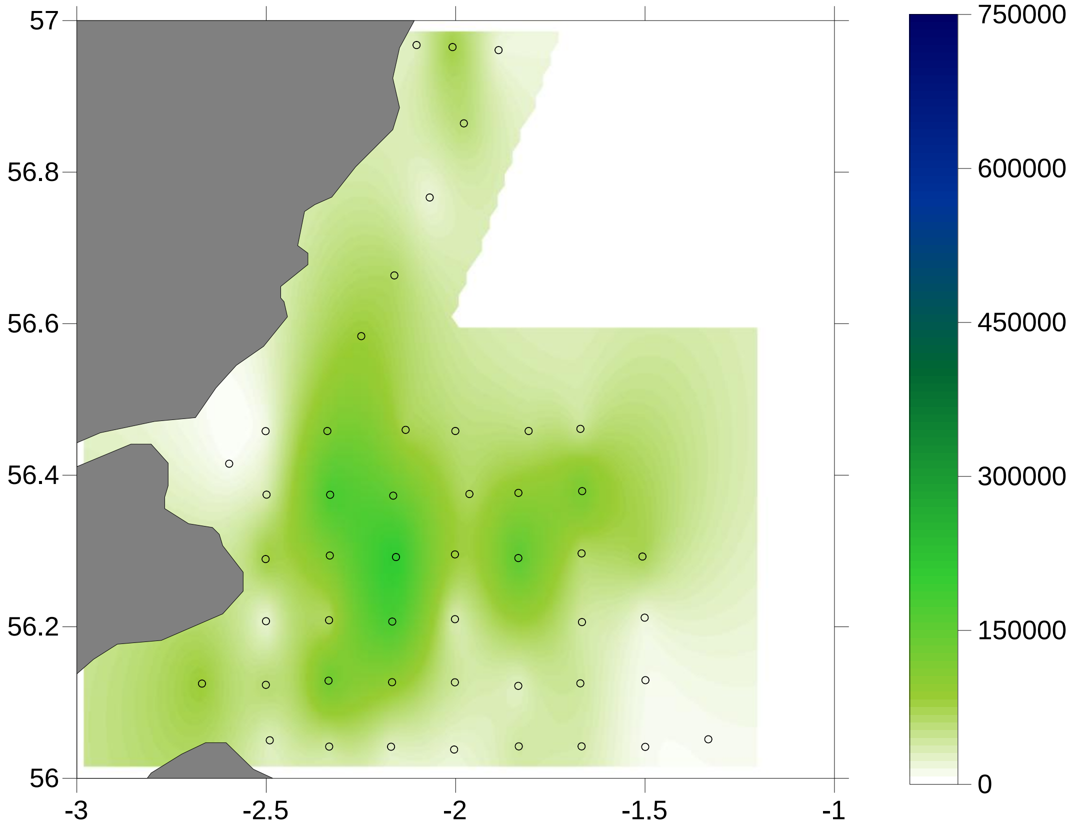

Figure 6: Map of the distribution of *A. clausii* stages CIII-CIV abundance in the study area in number of organisms m^{-2}.

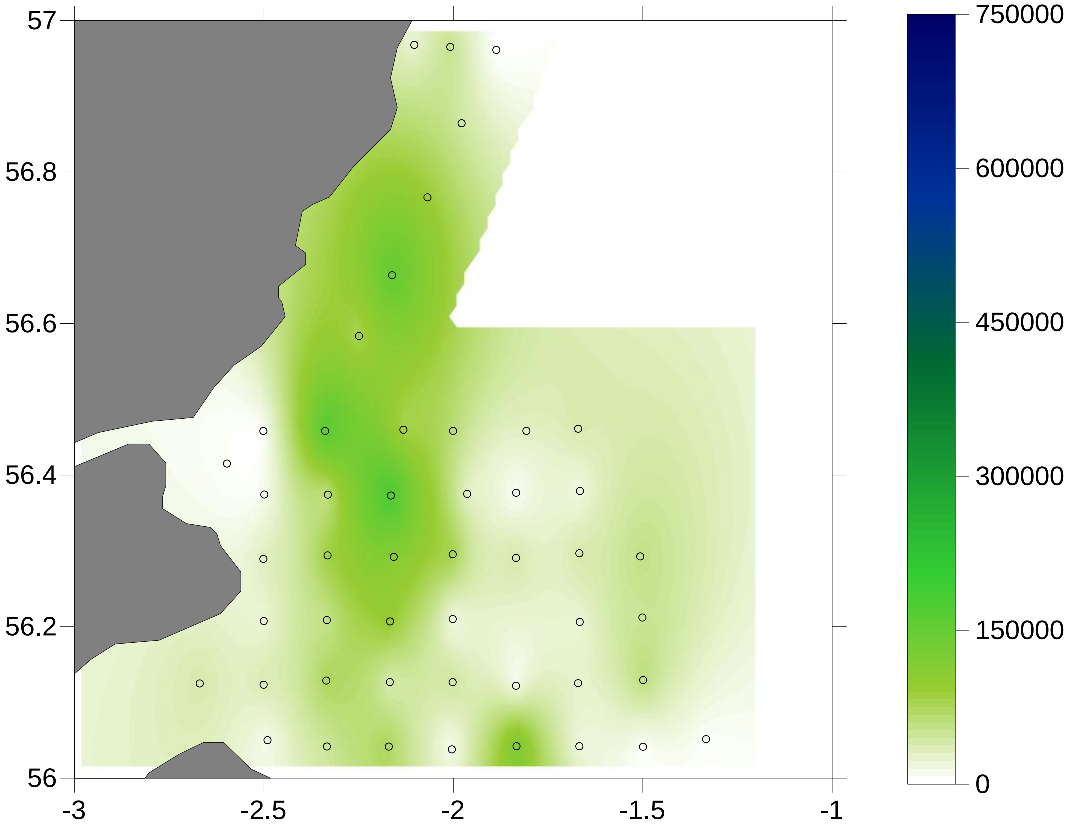

Figure 7: Map of the distribution of calanoid nauplii abundance in the study area in number of organisms m^{-2}.

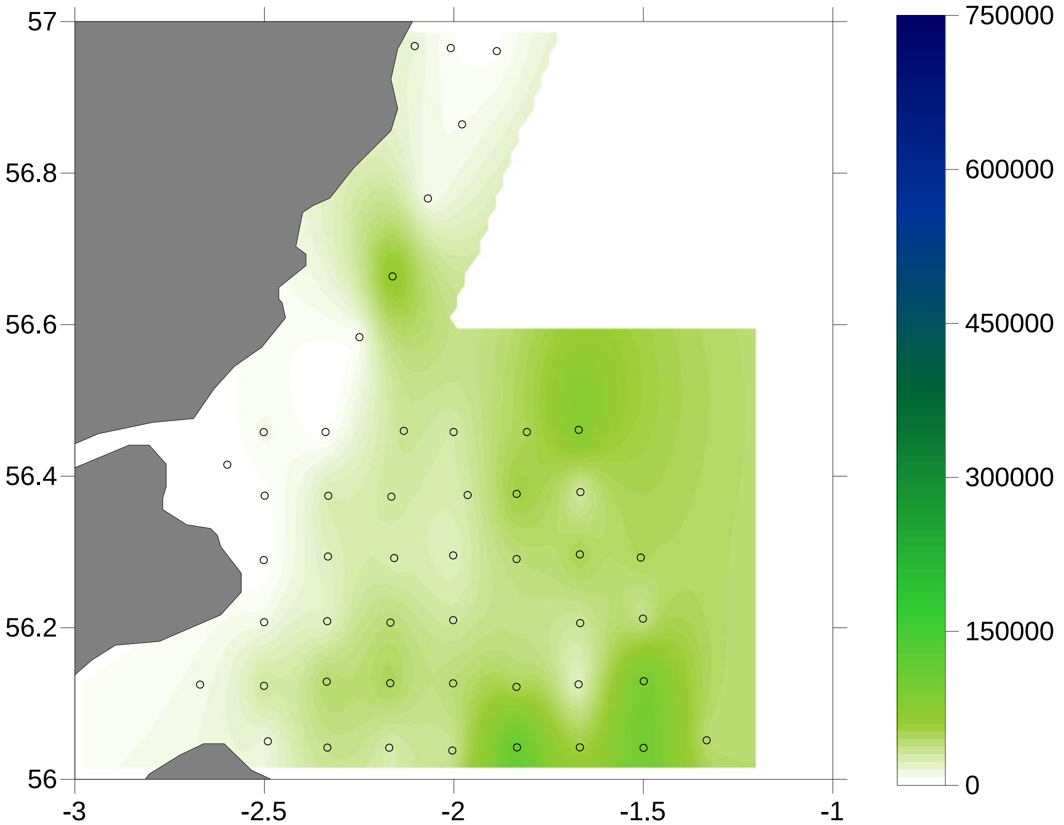

Figure 8: Map of the distribution of *T. longicornis* stages CV-CVI abundance in the study area in number of organisms m^{-2}.

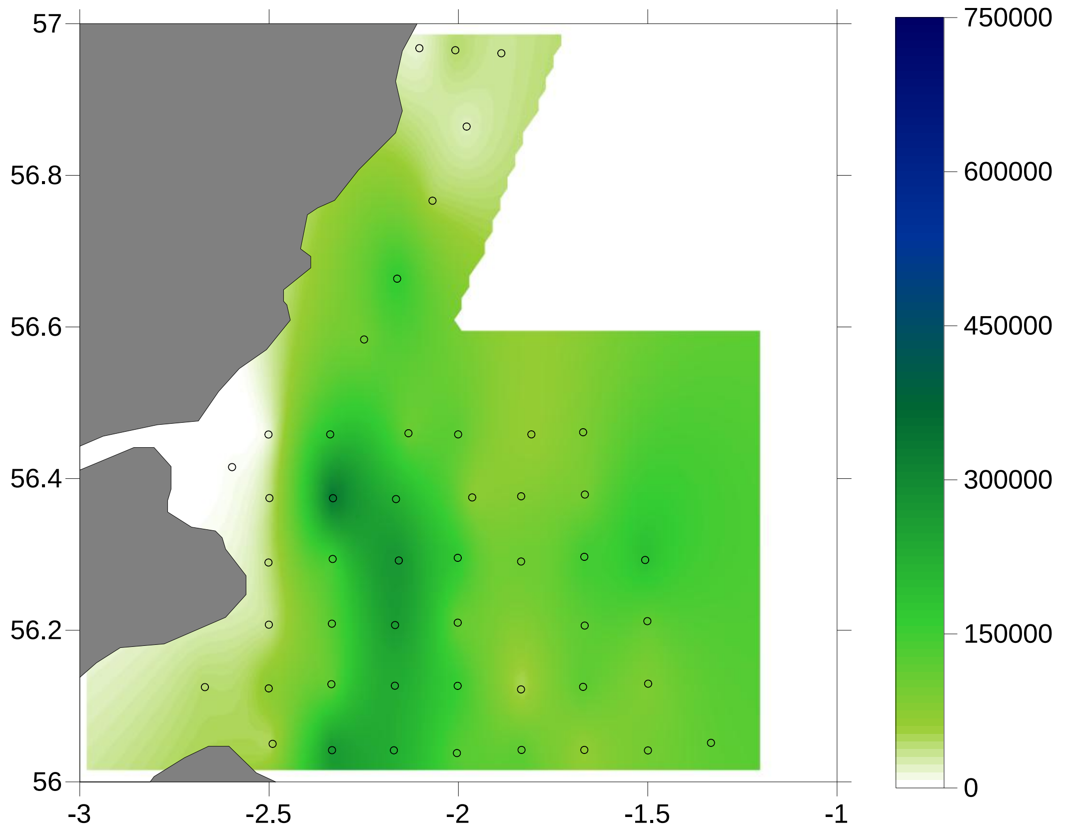

Figure 9: Map of the distribution of *Oithona* spp. CI-VI abundance in the study area in number of organisms m^{-2}.

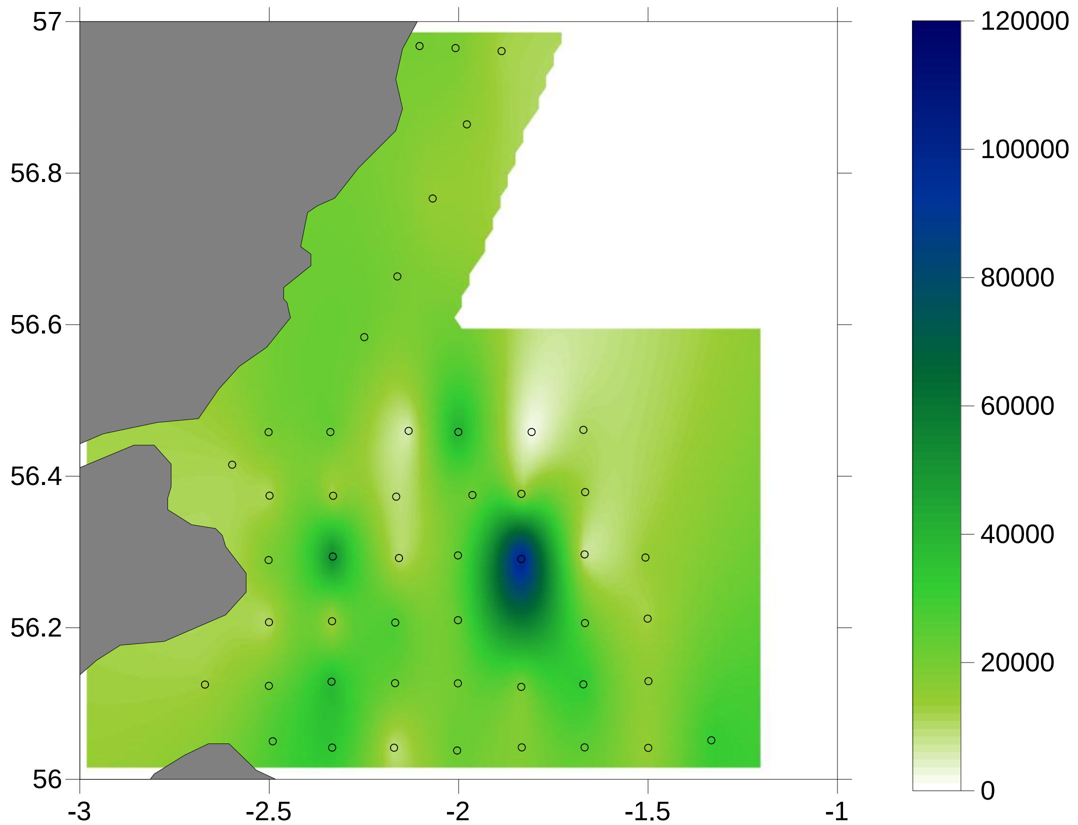

Figure 10: Map of the distribution of Appendicularia abundance in the study area in number of organisms m^{-2}. Note the different scale.

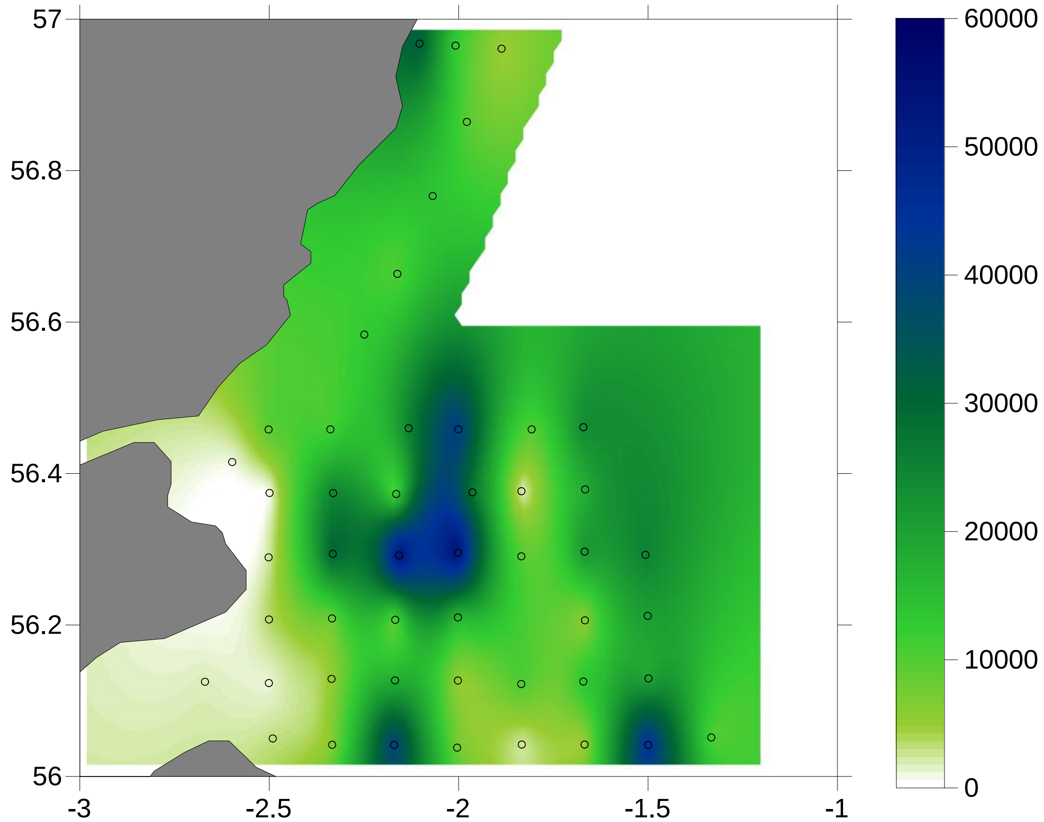

Figure 11: Map of the distribution of *T. longicornis* stages CIII-CIV abundance in the study area in number of organisms m^{-2}. Note the different scale.

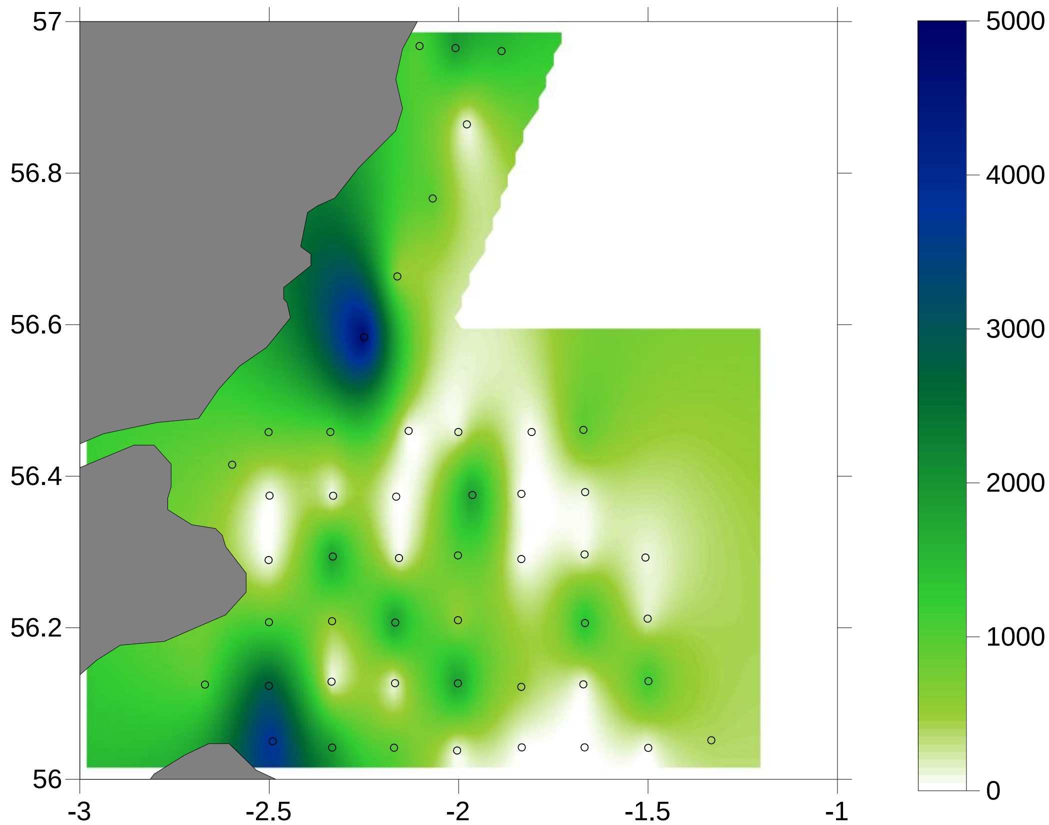

Figure 12: Map of the distribution of Cyprid abundance in the study area in number of organisms m^{-2}. Note the different scale.

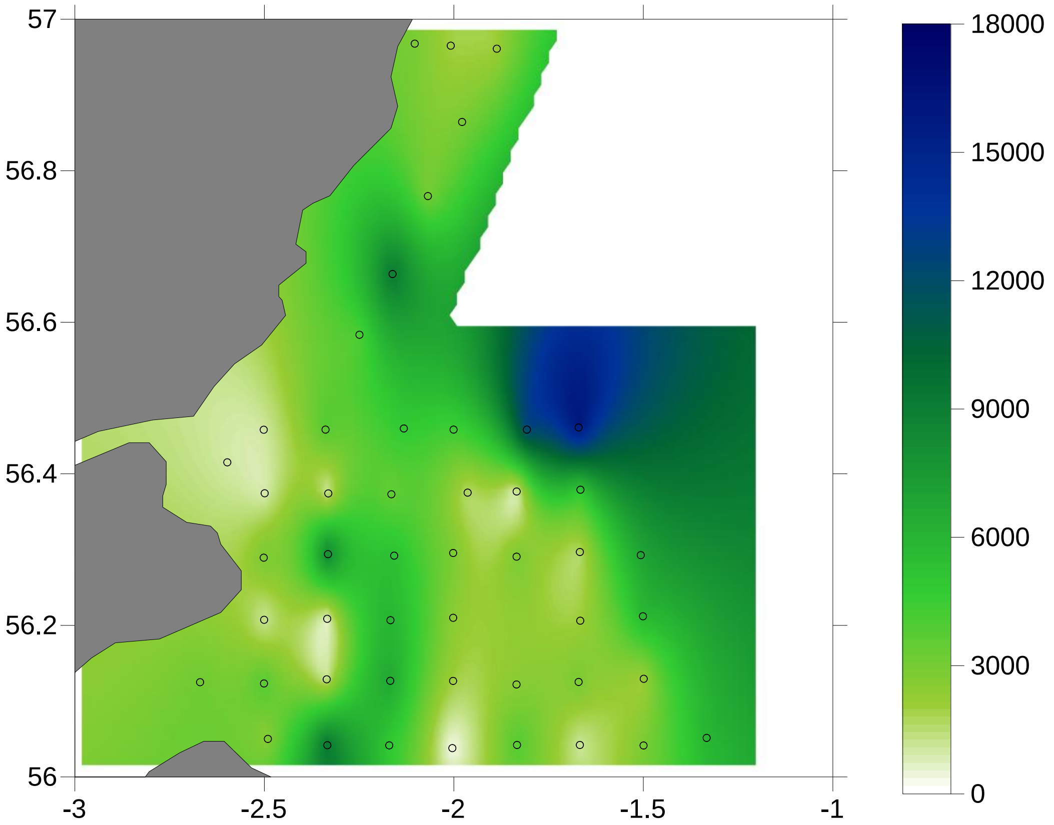

Figure 13: Map of the distribution of *C. hamatus* stages CV-CVI abundance in the study area in number of organisms m^{-2}. Note the different scale.

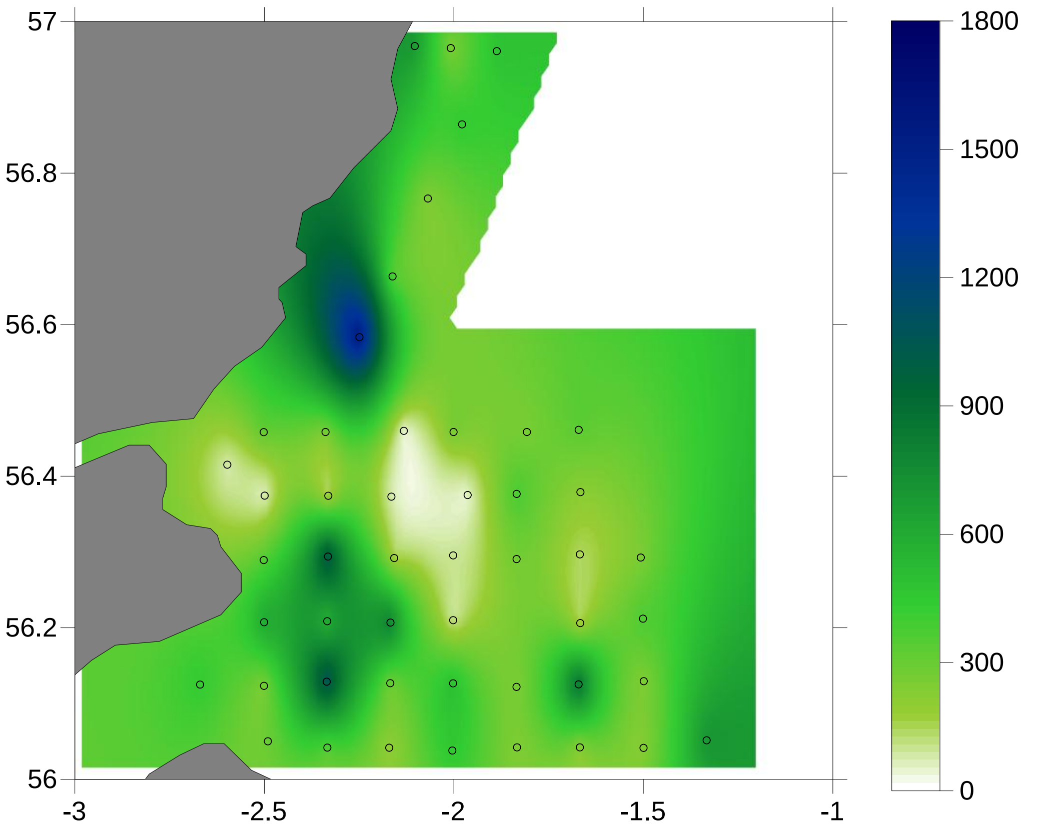

Figure 14: Map of the distribution of Decapod abundance in the study area in number of organisms m^{-2}. Note the different scale.

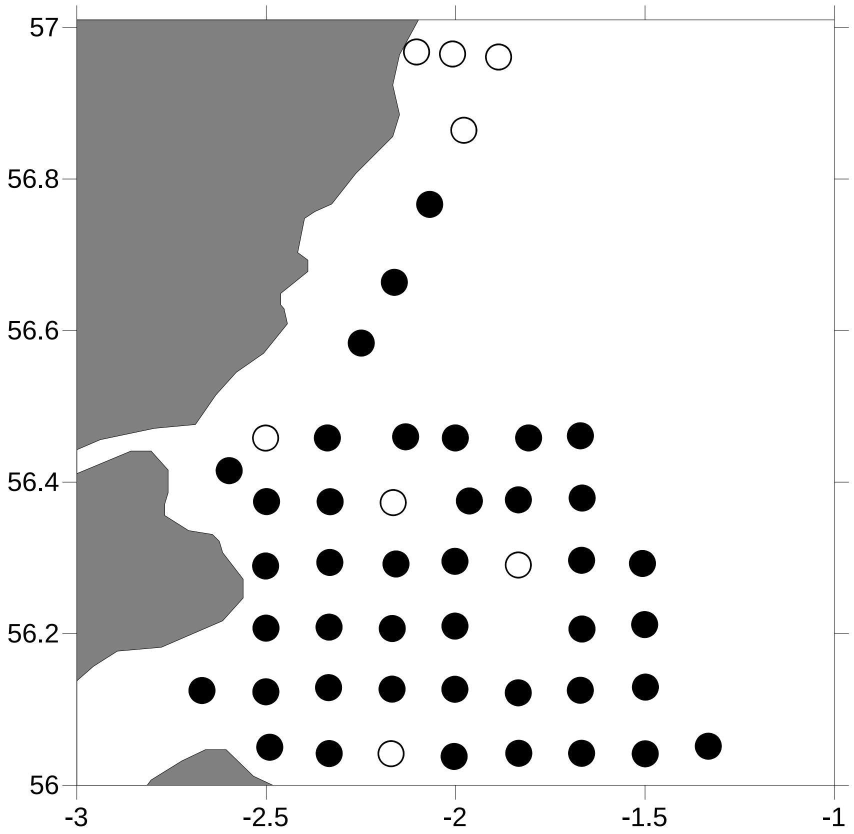

Figure 15: Presence (filed circles) or absence (empty circles) of fish eggs in the different stations analyzed in the study area.

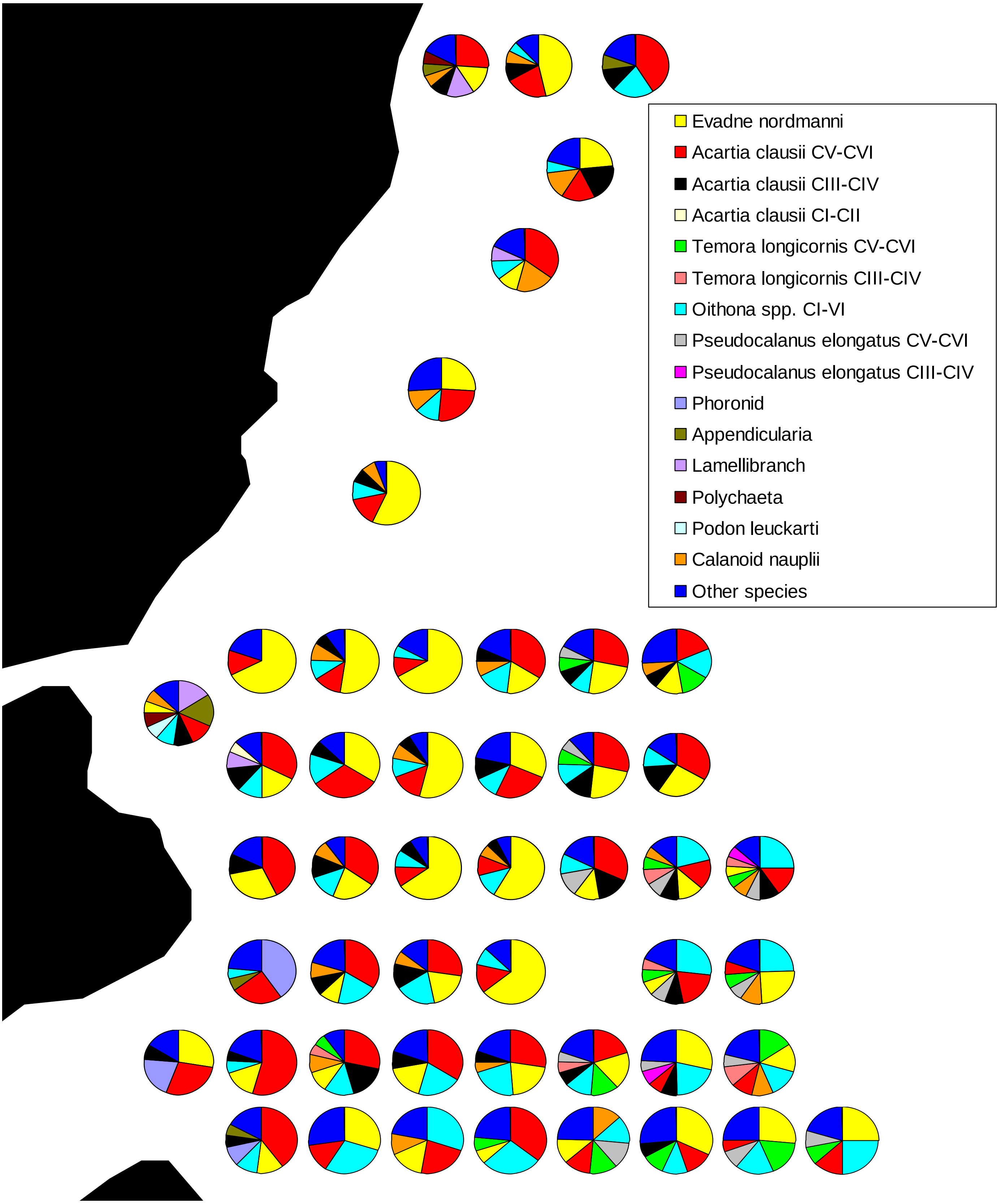

Figure 16: Geographical distribution of the relative taxonomic composition (species >5% of total abundance) on each zooplankton station in the study area.

Forage Fish Distribution

The highest abundance of sandeel was found to coincide with the position of swallow banks at station 53 (Figure 17), whereas high abundances were not found inshore and offshore of that area. In the case of herring, higher abundances were restricted to inshore areas (Figure 18). Finally, the distribution of sprat was concentrated inside the Firth of Forth (Figure 19), becoming lower further offshore.

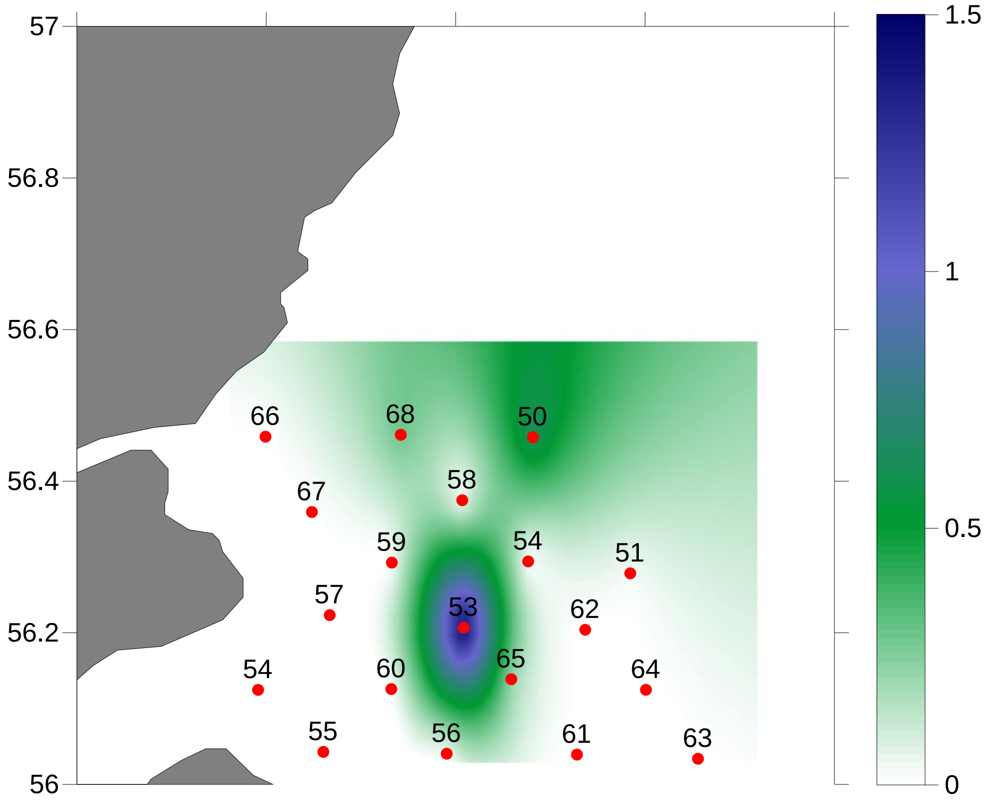

Figure 17: Map of the distribution of sandeel abundance in the study area in number of organisms m^{-2}. Note the different scale.

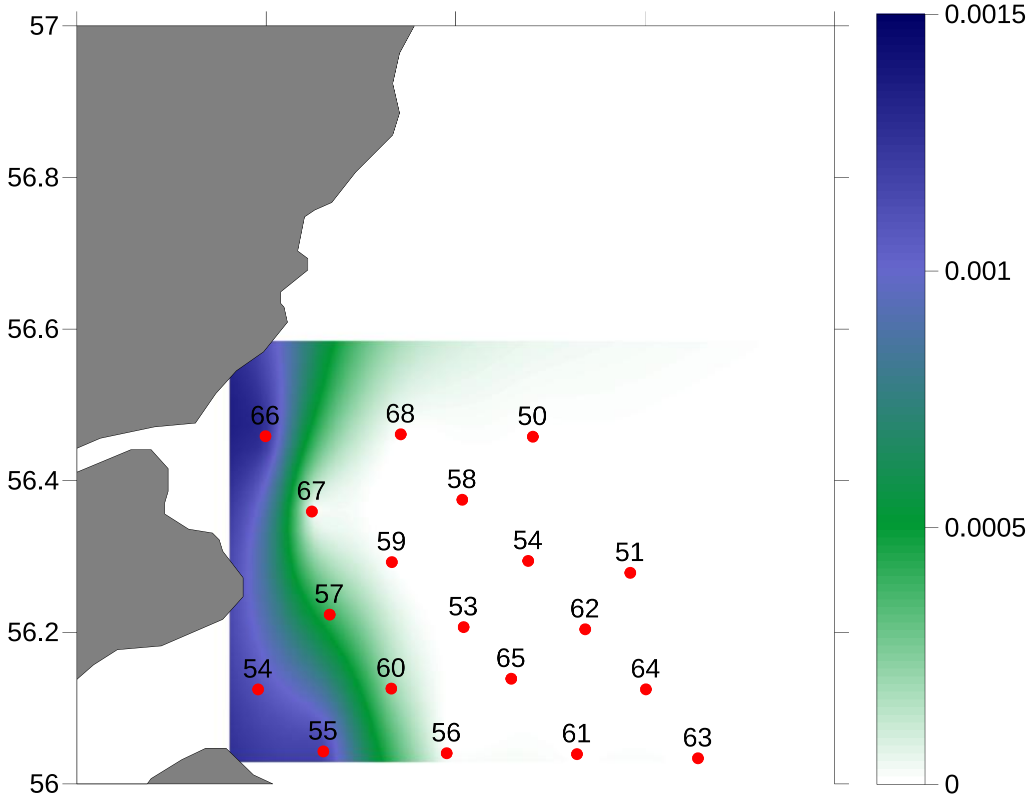

Figure 18: Map of the distribution of herring abundance in the study area in number of organisms m^{-2}. Note the different scale.

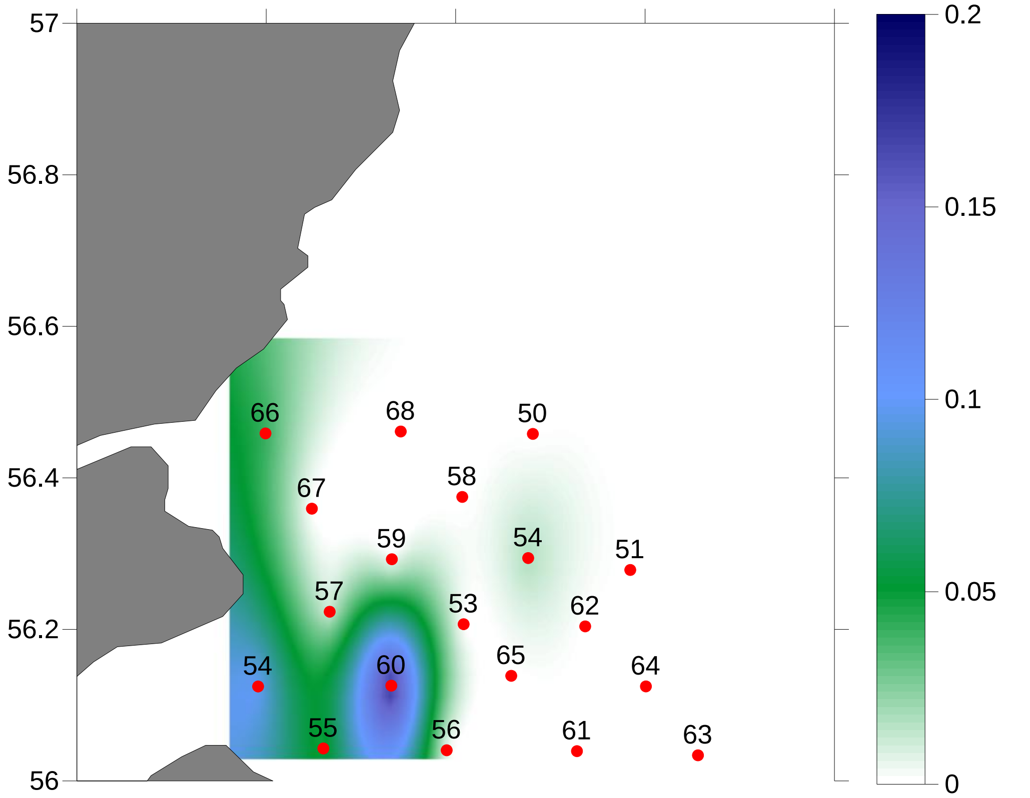

Figure 19: Map of the distribution of sprat abundance in the study area in number of organisms m^{-2}. Note the different scale.

Stomach Contents Analysis

Fish stomach data were also analysed from samples taken on cruise 0710A. The percentage of the different prey species found in the stomachs of sandeel, sprat and herring, were calculated and plotted.

The herring analysed for stomach contents ranged in length from 13.5-15.0 cm (Figure 20). The most abundant taxa in the stomachs of herring were *A. clausii* CV-CVI, fish eggs and cyprididae (Figure 21).

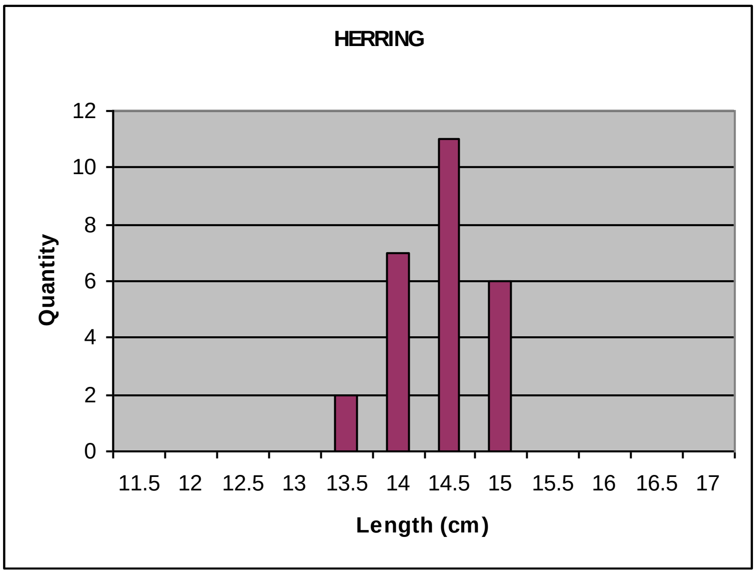

Figure 20: Length frequency distribution of herring used in stomach contents analysis (n=26)

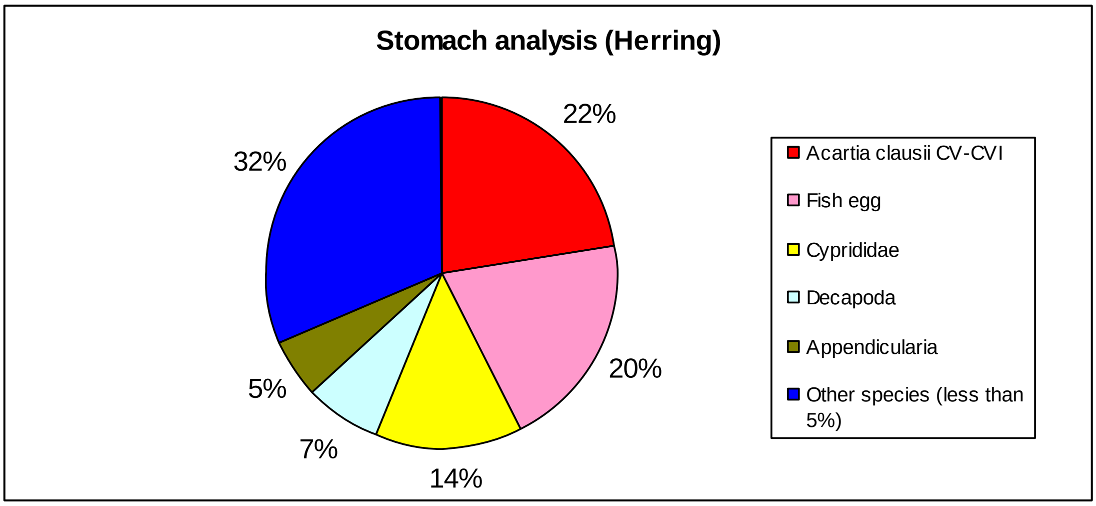

Figure 21: Relative abundance of the main prey items found in the stomachs of herring in the study area.

The sprat analysed for stomach contents ranged in length from 9.5–14.0 cm (Figure 22). In the stomachs of sprat, the most abundant taxon was *T. longicornis* CV-CVI (47% of the diet). Other copepods were also important (such as *C. hamatus* CV-CVI and *A. clausii* CV-CVI; Figure 23).

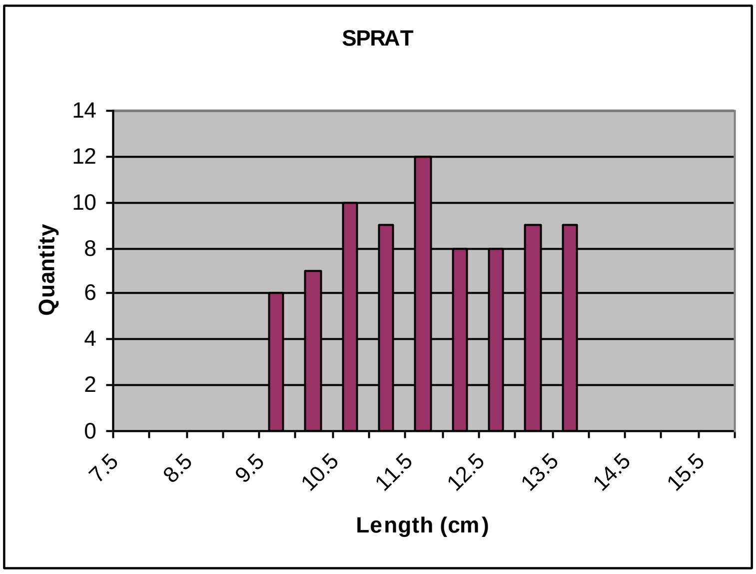

Figure 22: Length frequency of sprat used in stomach contents analysis (n=78).

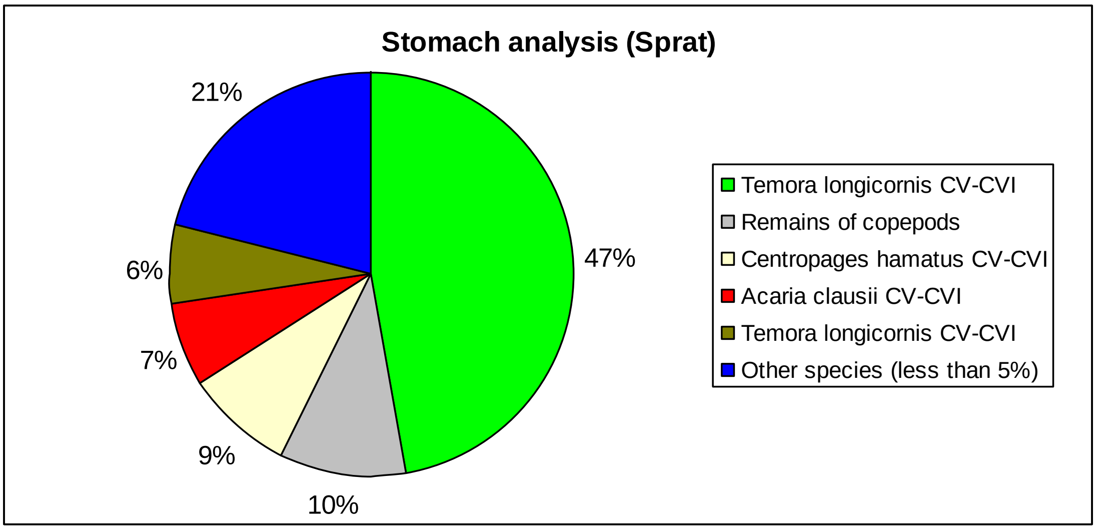

Figure 23: Relative abundance of the main prey items found in the stomachs of sprat in the study area.

The sandeel analysed for stomach contents ranged in length from 9.5–20.0 cm (Figure 24). The most abundant prey in the stomachs of sandeel were appendicularians (Figure 25-27). This was the case in all three size groups analysed small sandeel, 9.5-12.5 cm; medium sandeel 13.0-16.5 cm and large sandeel 17-20 cm.

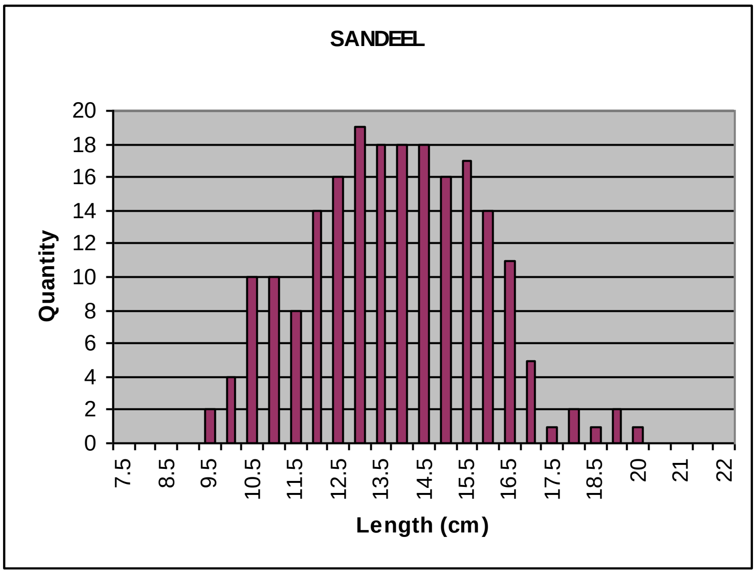

Figure 24: Length frequency of sandeel used in stomach contents analysis (n=207).

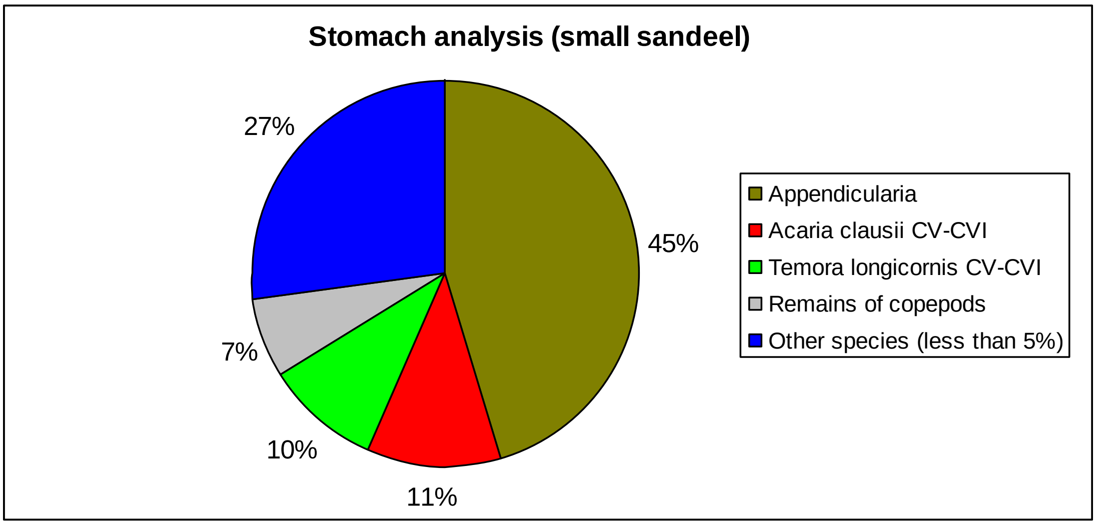

Figure 25: Relative abundance of the main prey items found in the stomachs of small sandeel in the study area.

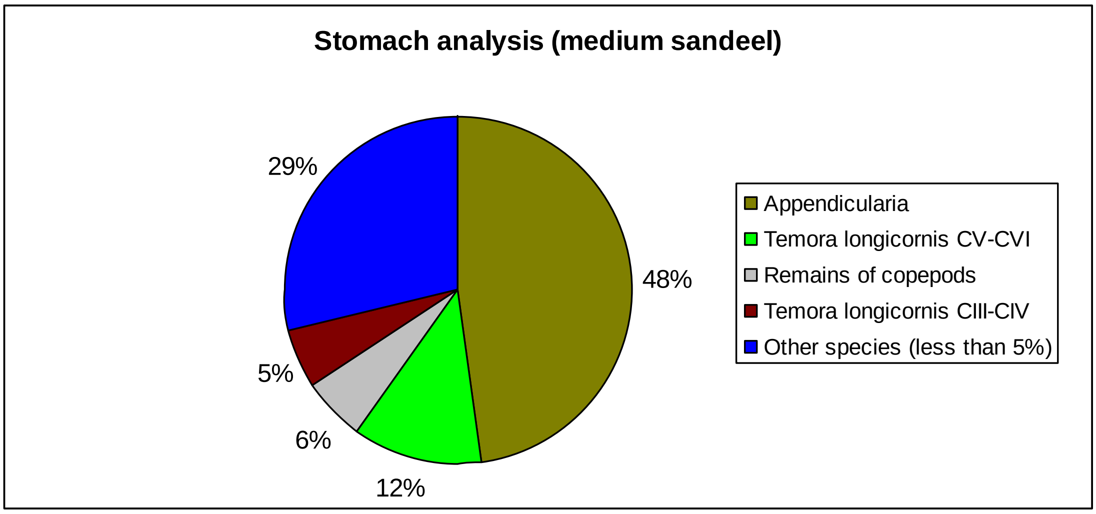

Figure 26: Relative abundance of the main prey items found in the stomachs of medium sandeel in the study area.

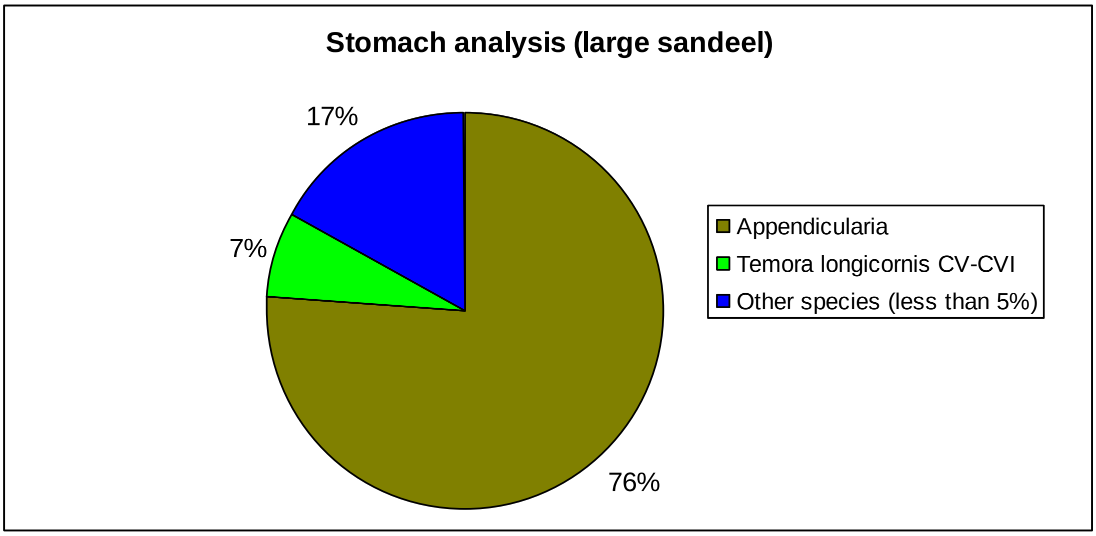

Figure 27: Relative abundance of the main prey items found in the stomachs of large sandeels in the study area.

Discussion

The results indicated that *E. nordmanni* was the most abundant species in the water column in the Wee Bankie study area but were not abundant in the stomachs of the herring, sprat and sandeel. In most cases, the most abundant prey consumed by these forage fish did not coincide with the most abundant zooplankton species.

Herring diet is very variable, depending on the area and the location of the study. For example, in the Baltic Sea (Casini *et al.,* 2004) the main prey item reported was *T.longicornis*. In the Norwegian Sea (Dalpadado *et al.,* 2000 and Prokopchuk and Sentyabov, 2006) the main prey was *C. finmarchicus,* although fish eggs and appendicularians were also important, depending on the season and the year. In the present study in the North Sea, off the east coast of Scotland, the most abundant prey in the herring diet were *A. clausii* CV-CVI (22% of the total), fish eggs (20%) and cyprid (14%). Although fish eggs were not counted in the zooplankton samples, just noted as present or absent, the area where herring were found was an area where fish eggs were present. Also, in station 36 of the zooplankton samples, there was a high density of *A. clausii* CV-CVI (Figure 5), which is an important prey for these fish, coinciding with a high abundance of herring. It is possible that both herring and their prey congregate in the same areas as a result of oceanographic conditions but herring may actively aggregate in areas of high suitable prey concentration.

In the case of sprat, the most abundant prey in their stomachs in the study area was *T.longicornis* CV-CVI (47% of the total of the diet) and also other copepods (adding up to more than 70% of the total). This is in contrast with the southern Baltic Sea, where the most important prey are *Podon intermedius*, *P. polyphemoides* and *Bosmina maritima* (Casini *et al.,* 2004). Comparing the relative distribution of fish and their prey, the distribution of sprat in the study area does not coincide with the areas of the highest abundance of *T. longicornis* CV-CVI. In terms of total abundance of zooplankton, sprat were found on stations of low zooplankton density. It is possible that these fish do not necessarily locate within areas of high suitable prey concentration and may need to travel greater distances to catch their prey, but it is also possible that lower prey concentrations may be sufficient to sustain the fish population. Alternatively, this spatial mismatch may be a sign of depletion of prey by consumption by fish.

The most abundant prey of sandeel in the study area of the North Sea were appendicularians, in contrast to the southwestern North Sea, where the most important prey were copepods (Macer, 1966). We split the sandeel into three length categories (small, medium and large sandeels) to account for possible length-related dietary differences. The results showed that there were differences in the diet among the size classes, not in the species composition but in their relative importance. The diets of small and medium sandeel were quite similar but, in the case of small sandeels, *A. clausii* CV-CVI were more important than for medium sandeel (11% and < 5% of the total in the diet, respectively). The most abundant prey of large sandeel, were Appendicularia, as in the case of the other two length groups, but in this case they represented 76% of their diet. Comparing areas of high abundance of Appendicularia with the distribution of total zooplankton, we can see that the station with highest abundance of Appendicularia does not coincide with the areas of highest zooplankton abundance nor the highest abundance of sandeel. As in the case of sprat, it is possible that the oceanographic conditions that favour high sandeel concentrations do not coincide with the most suitable areas for their prey, in which case sandeel may need to cover a greater distance to feed. It is also possible that sandeel populations can survive even at the lower prey concentrations observed, or that the spatial mismatch between sandeel and their prey may be the result of depletion of the food resource. In summary, further analysis will need to be carried out to explore the different alternatives.

Acknowledgements

Guillermo Gomez Garcia was funded for 6 months (between 1 April and 30 September 2011) by the Leonardo da Vinci Program of the European Commission from the University of Las Palmas de Gran Canaria (FULPGC). Guillermo was hosted in the Zooplankton Ecology Group, Marine Scotland Science, Marine Laboratory Aberdeen and supervised by Alejandro Gallego (Oceanography Group).

Guillermo would like to thank Robert Watret and Alejandro Gallego for instruction on how to use Golden Software Surfer 8 to grid and plot the data, Steve J. Hay, John Fraser, Kathryn Cook, Michael Penston, Susan Robinson and Jens Rasmussen for tuition on zooplankton taxonomic analysis, Íñigo Martínez for help with graphics and pie charts and Simon Greenstreet for providing information about the Firth of Forth study area.

References

Macer, C.T. 1966. Sandeels (Ammodytidae) in the south-western North Sea: their biology and fishery. MAFF Fishery Invest. London Ser. II. 24, 1-55.

Simon P. R. Greenstreet, Gayle J. Holland, Emma J. Guirey, Eric Armstrong, Helen M. Fraser and Ian M. Gibb, 2010. Combining hydroacoustic seabed survey and grab sampling to assess "local" sandeel population abundance. ICES J. Mar. Sci., 67: 971-984.

Francis Daunt, Sarah Wanless, Simon P.R. Greenstreet, Henrik Jensen, Keith C. Hamer and Michael P. Harris, 2008. The impact of the sandeel fishery closure on seabird food consumption, distribution, and productivity in the northwestern North Sea. Can. J. Fish. Aquat. Sci., 65: 362-381

Villy Christensen, 2010. Behavior of Sandeels Feeding on Herring Larvae. The Open Fish Science Journal, 3, 164-168.

Michele Casini, Massimiliano Cardinale and Fredrik Arrhenius, 2004. Feeding preferences of herring (*Clupea harengus*) and sprat (*Sprattus sprattus*) in the southern Baltic Sea. ICES J. Mar. Sci., 61: 1267-1277.

Irina Prokopchuk and Evgeniy Sentyabov, 2006. Diets of herring, mackerel, and blue whiting in the Norwegian Sea in relation to *Calanus finmarchicus* distribution and temperature conditions. ICES J. Mar. Sci., 63: 117-127.

P. Dalpadado, B. Ellertsen, W. Melle and A. Dommasnes, 2000. Food and feeding conditions of Norwegian spring-spawning herring (*Clupea harengus*) through its feeding migrations. ICES J. Mar. Sci., 57: 843-857.

Robert W. Furness, 2003. Impacts of fisheries on seabird communities. Sci. Mar., 67 (Suppl. 2): 33-45.

R.W. Furness and Kees (C.J.) Camphuysen, 1997. Seabirds as monitors of the marine environment. ICES J. Mar. Sci., 54: 726-737.

The Scottish Government

ISBN: 978-1-78256-005-0 (web only)

ISSN: 2043-7722

APS Group Scotland
DPPAS13279 (08/12)

w w w . s c o t l a n d . g o v . u k