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MONEOS

Mesozooplankton

Eindrapport 2011- 2013

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in samenwerking met

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Content **page**

Samenvatting	3
Abstract	4
Introduction	5
Material and methods	5
Results	7
Discussion	35
References	39

Samenvatting

Mesozooplankton abundantie is opgevolgd in de Westerschelde gedurende mei 2011- december 2011, en maart-oktober 2012 en 2013, op de stations Breskens, Terneuzen, Hansweert en Bath. Zandvliet/Boei 87. Dit rapport analyseert de globale tendensen uit deze drie jarige periode, integreert deze gegevens met de OMES zooplankton data uit de Zeeschelde en maakt een eerste vergelijking met mesozooplankton observaties in de periode 1989-'90. Ten slotte worden enkele pistes voor zooplankton onderzoek binnen MONEOS en op internationaal vlak gesuggereerd.

De Westerschelde vertoont tussen 2011 en 2013 een lage zooplankton diversiteit, maar dit is ten dele te wijten aan het groeperen van sommige taxa (larven, bv). De geïntroduceerde Aziatische soort, *Pseudodiapotomus marinus,* die in 2011 werd waargenomen, was afwezig gedurende 2012 en 2013.

Zowel in de tijd als in de ruimte vertonen de abundantie gegevens grote variatie van jaar tot jaar, wat normaal is voor een zooplankton gemeenschap in een dynamisch systeem als de Westerschelde. Ondanks de aanzienlijke variabiliteit zijn enkele algemene tendensen waar te nemen. De abundantie van de meeste groepen (larven en mariene copepoden) neemt af van stroomafwaarts naar stroomopwaarts. Alleen de calanoide copepode *E. affinis* vertoont een toenemende abundantie in stroomopwaartse richting.

Via multivariate analyse werd de spatio-temporele distributie van het 2011-2013 Westerschelde mesozooplankton gerelateerd aan de omgevingsvariablen gebaseerd op de 3 jaar observaties. Deze analyse toont dat de zooplankton taxa distributie gerelateerd is aan de saliniteitgradient, met enerzijds saliniteit geassocieerd met transparantie, overeenkomend met station Breskens, en anderzijds de zone Zandvliet/Boei 87 geassocieerd met hoge concentraties aan zwevende stof, organisch particuliair koolstof en nutrienten. Larven en de marine copepooden *Temora longicornis* en *Centropages hamatus*, en de cladoceren *Evadne* and *Podon* zijn typisch geassocieerd met de transparantie/d saliniteits vector, terwijl *E. affinis* en 'andere clanoiden' geassocieerd zijn met de nutrient-geladen stroomopwaartse zone. Een andere groep organismen is duidelijk geassocieerd temperatuur: de 'mariene' copepoden als *E. acutifrons, O. brevicornis, Pseudocalanus sp*. Tenslotte zijn groepen als bv. copepode nauplii, calanoide copepodieten en ciripeda nauplii minder sterk geassocieerd met de omgevingsfactoren, wat betekent dat ze op meer variable wijze op de verschillende stations en in de tijd voorkomen. Inderdaad, de stations tussen Breskens and Zandvliet/ Boei 87 vormen - op basis van de zooplankton gemeenschap als functie van de omgevingsvariabelen - een continuum tussen deze extremen met overlap tussen de posities van elk station. Dit patroon variëert ook weinig tussen de drie jaren. Opvallen is dat er geen zooplankton taxa sterk geassocieerd zijn met Chla, phaeopigmenten en zuurstof concentratie. Dit is mogelijk te verklaren door een – eveneens opmerkelijke - associatie van zuurstof en NH4.

De compilatie van de Westerschelde en Zeeschelde mesozooplankton distributies toont aan dat de zooplankton gemeenschap over het gehele Schelde estuarium een bimodale distributie vertoont. Calanoiden zijn vooral stroomopwaarts abundant, cyclopoiden komen in vergelijkbare abundantie stroomafwaarts en stroomopwaarts en meroplanktonische larven en harpacticiden zijn hoodfzakelijk stroomafwaarts te vinden. In feite ligt het station Zandvliet/Boei 87 op de grens van ecotoop – zone met lage zooplankton abundante. Deze zone is interessant omdat ze de gelegenheid biedt om de tolerantie van verschillende taxa voor variërende omgevingscondities te bestuderen. Dit is bijzonder

het geval voor de calanoide copepode *E. affinis*, die recentelijk zijn maximum abundante stroomopwaarts, naar de Zeeschelde heeft verplaats. Het zou interessant zijn om het zooplankton abundantie en diversiteits patroon in de Schelde als testcase te gebruiken in de aan gang zijnde discussie over de 'Remane curve' in estuaria.

Vergelijking met eerder geobserveerde zooplankton abundanties in de periode 1989-1991 (Soetaert & Van Rijswijk, 1995) en de huidige waarnemingen in de Westerschelde toont aan dat er geen significantie wijzigingen zijn in de abundantie van copepoden op niveau van de orders calanoiden, cyclopoiden en harpacticiden. Een meer gedetailleerde vergelijking is mogelijk, maar kon vanwege verschillen in identificatie niveau niet binnen deze studie worden uitgevoerd.

Ten slotte is het geruststellend dat vergelijking van de abundantie resultaten verkregen uit de MONEOS stamnamen en de OMES staalnamen geen significant verschillende resultaten opleveren voor de meeste taxa. Dit zal verdere analyse van gecompileerde datasets en vergelijking met eerdere gegevens vergemakkelijken.

In dit perspectief stellen bieden de zooplankton gegevens dus de mogelijkheid om de capaciteit van aanpassing van verschillende taxa aan variërende omgevingsfactoren te onderzoeken, via combinatie van OMES en MONEOS gegevens. De overgang tussen de zout- en zoetwater zooplankton gemeenschap in de Schelde verloopt niet continu, maar bimodaal. De interacties tussen beide gemeenschappen op lange termijn - zoals bv het veranderen van de maximale abundantie van de copepode *E. affinis,* van brakwater naar zoetwater - zijn te relateren aan wijzigingen in waterkwaliteit (vooral in de Zeeschelde), maar mogelijk ook aan andere beleids-gerelateerde aspecten zoals hydrodynamische en morfologische wijzigingen in het estuarien continuüm. In combinatie hiermee zou een evaluatie van de zooplankton potentiële graasdruk op het fytoplankton, en vooral als percentage van de primaire productie interessant zijn als een mogelijke verklarende factor voor belangrijke veranderingen in bv chl *a* concentraties, waargenomen in zowel de Zeeschelde als de Westerschelde.

Op internationaal vlak, bestaat, via het project 'BIOFOZI', dat de zooplankton gemeenschap in het stroomgebied van de Schelde (regio Nord Pas De Calais, Frankrijk en een continuüm met de meest stroomopwaartse OMES stations) de mogelijkheid om de zooplankton gemeenschap over de gehele loop van de Schelde - van bron tot monding - te volgen en te relateren aan de omgevingsvariabelen.

Abstract

Mesozooplankton abundance has been monitored in the Westerschelde twice a month from Mai till December 2011 and monthly from March till October in 2012 and 2013 at stations Breskens, Terneuzen, Hansweert and Bath. Available data from the OMES project on station 'Zandvliet/Boei 87' were included in the results. This report presents a combination of the results of these 3 years observations.

Zooplankton in the Westerschelde generally shows a low diversity, but this is partially due to the use of grouped taxonomic identification for some organisms, such as meroplanktonic larvae.

Abundance for all groups, except for calanoids, decreases from the mouth till the upstream station. Multivariate analysis shows this tendency to correspond to the salinity, with on the one hand typical marine copepods and such as *T. longicornis* , *C. hamatus* and the cladocernas *Podon* and *Evadne* being associated with salinity and transparency, and on the other extreme calanoids such as *E. affinis* associated with the upstream area show high concentrations of SPM, POC and nutrients. Other copepods, such as *E. acutifrons, O. brevicornis* and *Pseudocalanus* sp. are clearly associated with temperature. Remarkable is that little association is observed between zooplankton taxa distribution and Chl *a* and oxygen concentration.

Compiling data from this study with zooplankton distribution patterns in the Zeeschelde (OMES project) show that, over the entire Schelde estuary, the zooplankton community demonstrates a bimodal distribution. Calanoids are much more abundant upstream than downstream, cyclopoids are present in more comparable abundance downstream and upstream, and meroplanktonic larvae and harpacticoids are much more abundant downstream than upstream. In between these two zone (roughly between km 43 and 121 from the mouth, very little zooplankton occurs. This zone corresponds to the 'low diversity' zone of the Remane curve, and the Schelde as such provides an interesting test case for the ongoing discussion about the validity of this concept in estuaries in general.

Zooplankton abundance, observed in this study, does not significantly differ from abundance observed for calanoids, cyclopoids and harpacicoids during 1989- '91 (Soetaert & Van Rijswijk, 1993).

The fact that abundance results obtained from MONEOS and OMES samplings do not significantly differ for most taxa considered, opens perspectives for further comparison with previous zooplankton data, and for further integrated studies on the entire Schelde estuary in a fundamental and management related context. At international scale, the possibility at present exists to study the Schelde zooplankton community as a function of environmental conditions from the source till the mouth.

1. Introduction

The research carried out mesozooplankton in the frame of the MONEOS project aims at following the evolution of the zooplankton composition and its spatio-temporal distribution in the Westerschelde estuary. Because of its central position as a link between primary production and higher food levels, zooplankton is an essential component in the functioning of any aquatic ecosystem. Its drifting with the currents also makes it a good indicator of spatio-temporal variation in hydrological and concurrent water quality conditions.

The present document reports on the data of 2,5years (May 2011-December 2013) monthly (biweekly in 2011) samplings along the salinity gradient in the Westerschelde (Schelde on Dutch territory, km 0-km 57 from the mouth at Vlissingen).

2. Material and Methods

Mesozooplankton abundance was monitored in the Westerschelde between May 2011 and December 2013, two times a month between May and September 2011 and once a month in October and November at stations Breskens, Terneuzen, Hansweert and Bath. In 2012 and 2013, one campaign per month was analysed from March to October. The station 'Zandvliet was sampled, but the data presented here are abundances observed at very nearby 'Boei 87' of the OMES project, for which copepod nauplii and meroplanktonic larvae were analysed in the 2012 samples (which is not currently done for the OMES samples) for compatibility with the Westerschelde data. For the 2013 samples, station Zandvliet was analysed and compared with the data from station 'Boei 87' from the OMES project.

The salinity range observed during the three years study transects is given in Fig. 2.1, showing a clear decrease in salinity at all stations in the beginning of the winter for all years. The observed salinity range is similar for all at stations Breskens, Terneuzen and Hansweert. Station Zandvliet/Boei 87 showed lower salinity during summer 2012 than during summer 2011.

Sampling is carried out by NIOZ. At each station of Westerschelde, 150-250 L of water are taken at sub-surface with a pump having a flow 300L/min and filtered through a 50 µm net. We note that for the 2011-2012 'Zandvliet/Boei 87' samples, only 50 L of water was taken with a bucket at sub-surface. The collected mesozooplankton is put is a plastic container (filled up to 90 mL) and, fixed with 40 % formalin (final concentration 4 %) resulting a 100 mL concentrated sample. Samples are sent to EcoLab, Toulouse. In the laboratory, depending upon the zooplankton density, 2,5-30 mL subsamples (2-20% of the sample) are analysed under binocular microscope (magnification 10-90x) for determination and abundance quantification.

Determination is carried out at species level when possible. For copepods this is possible from copepodids 5 (C5) onwards. The smaller copepodids (C1-C4) are grouped into calanoids, cyclopoids and harpacticoids. Young stages are identified as copepod nauplii, cirriped nauplii, cirriped larvae, zoe larvae, mollusc larvae and polychaete larvae and cladocerans. Most important references used are: Dussart, 1967; Dussart, 1969; Kiefer, 1978; Amoros, 1984; Margaritora, 1985, Einsle, 1996, Karaytug, 1999, Ueda, 2003.

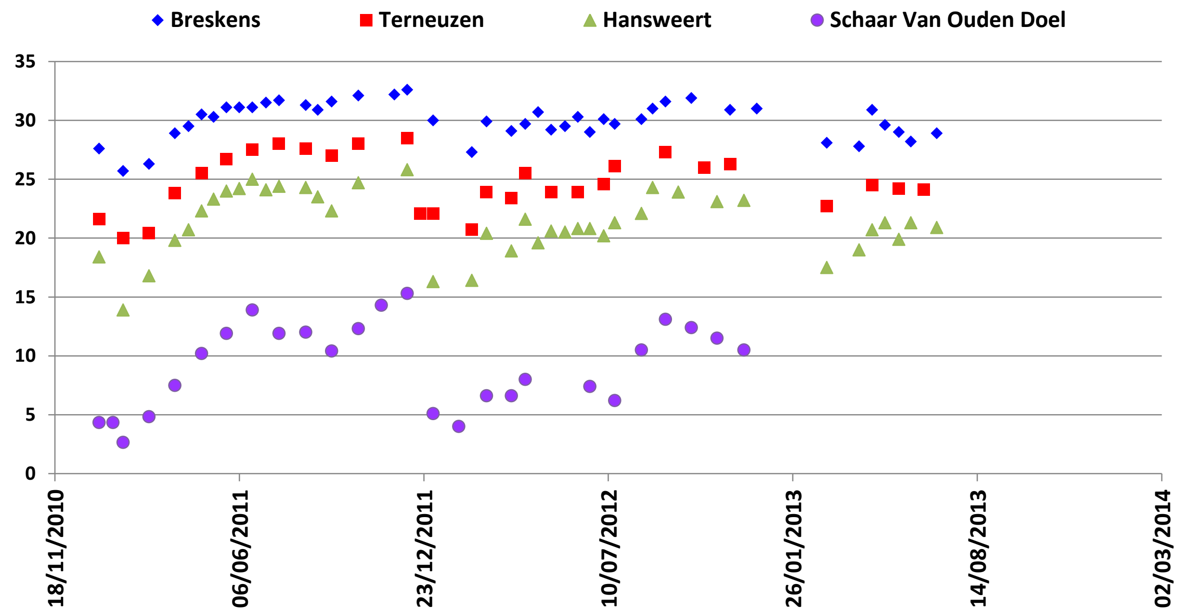


Fig. 2.1. Salinity observed at the sampling stations during 2011-2013. The station 'Schaar van Ouden Doel' can be considered to represent 'Zandvliet/Boei 87'.

Environmental data were provided from the Rijkswaterstaat and NIOZ database by G. Spronk and J. Kromkamp, respectively. Because of the best fit concerning dates environmental data and zooplankton data, NIOZ data were used for multivariate analysis.

Graphics and data analysis: all graphic presentations were made in Microsoft Excel 2007. Non parametrical tests and boxplot graphs were performed with Statistica 6 (version 6.0; Statsoft Inc., Tulsa, USA). Difference of abundance were tested by a Mann-Whitney test and tendencies with time/space using a Kendall-Tau test (both at $p<0.05$).The CANOCO software package, version 4.5 (ter Braak, 1987, 1994) was used for multivariate analysis.

3. Results

3.1 Taxonomic composition

The zooplankton of the Westerschelde is taxonomically dominated by copepods. 6 calanoid copepods, 1 cyclopoid copepod and 1 harpacticoid copepod could be identified at species level (Table 3.1). No new species were found in 2012 or 2013 as compared to the taxonomic list reported for 2011.

In previous reports, we reported *Acartia bifilosa* as an important downstream species. More detailed analysis showed this taxon to be essentially *Acartia clausi*, but occasionally *A. tonsa* is also observed. As distinction between these two species cannot be done under binocular microscope, we maintain *Acartia* spp., knowing that this taxon concerns essentially *A. clausi*.

Table 3.1 Species names of taxa identified at species level.

Number	Taxa	Authors	Zooplankton copepod	References
1	*Eurytemora affinis*	(S.A. Poppe, 1880)	Calanoid Copepod	TWN list
2	*Acartia* spp.	(W. Giesbrecht, 1881)	Calanoid Copepod	TWN list
3	*Pseudodiaptomus marinus*	Sato, 1913	Calanoid Copepod	TWN list
4	*Temora longicornis*	(Muller O.F., 1785)	Calanoid Copepod	TWN list
5	*Centropages hamatus*	(Lilljeborg, 1853)	Calanoid Copepod	TWN list
6	*Oithona brevicornis*	Giesbrecht, 1891	Cyclopoid Copepod	TWN list
7	*Euterpina acutifrons*	(Dana, 1847)	Harpacticoid Copepod	TWN list

3.2 Abundance and spatio-temporal distribution

During all years, copepod nauplii and mero-planktonic larvae of bivalve numerically dominated the mesozooplankton community at all stations, reaching maximal abundances of up till around 500.10^3 ind. m^{-3} at station Breskens in 2013, and between roughly $40\text{-}80.10^3$ ind.m^{-3} for the more downstream stations (Fig. 3.1). With few exceptions, copepod nauplii dominate in abundance at all stations and times. Peak periods for copepod nauplii were August-October in 2011, but April-May in 2012. In 2013, copepod nauplii peaked in august at the downstream stations Breskens and Terneuzen, but during spring at the more upstream stations. The mero-planktonic organisms occured almost throughout the year, showed occasional peak abundance in spring, especially at Terneuzen and Hansweert during 2011. The meroplanktonic larvae were strongly dominated by bivalve larvae. Polychaete, cirripeda and gastropod larvae occurred mainly at stations Terneuzen and Hansweert. While no data for station Zandvliet/Boei 87 on these organisms were available for 2011, we notice that 2012 and 2013 abundances at this station are comparable to those observed at Bath.

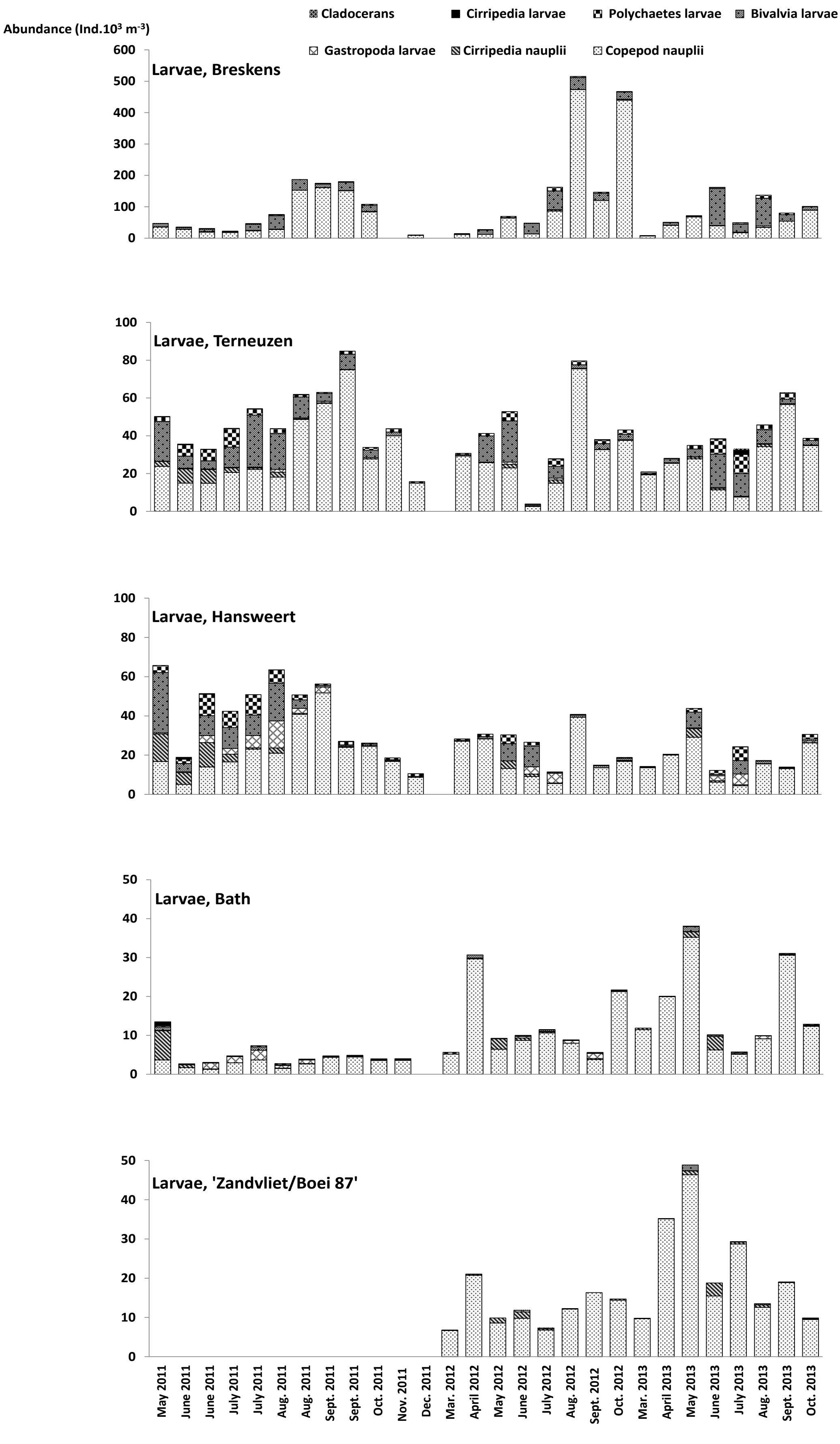


Fig. 3.1. Abundance of copepod nauplii and meroplanktonic larvae at each station, observed twice a month between May and November 2011 and once a month between March and October in 2012 and 2013. Copepod nauplii and meroplanktonic larvae were not quantified at station Zandliet/Boei87 during 2011.

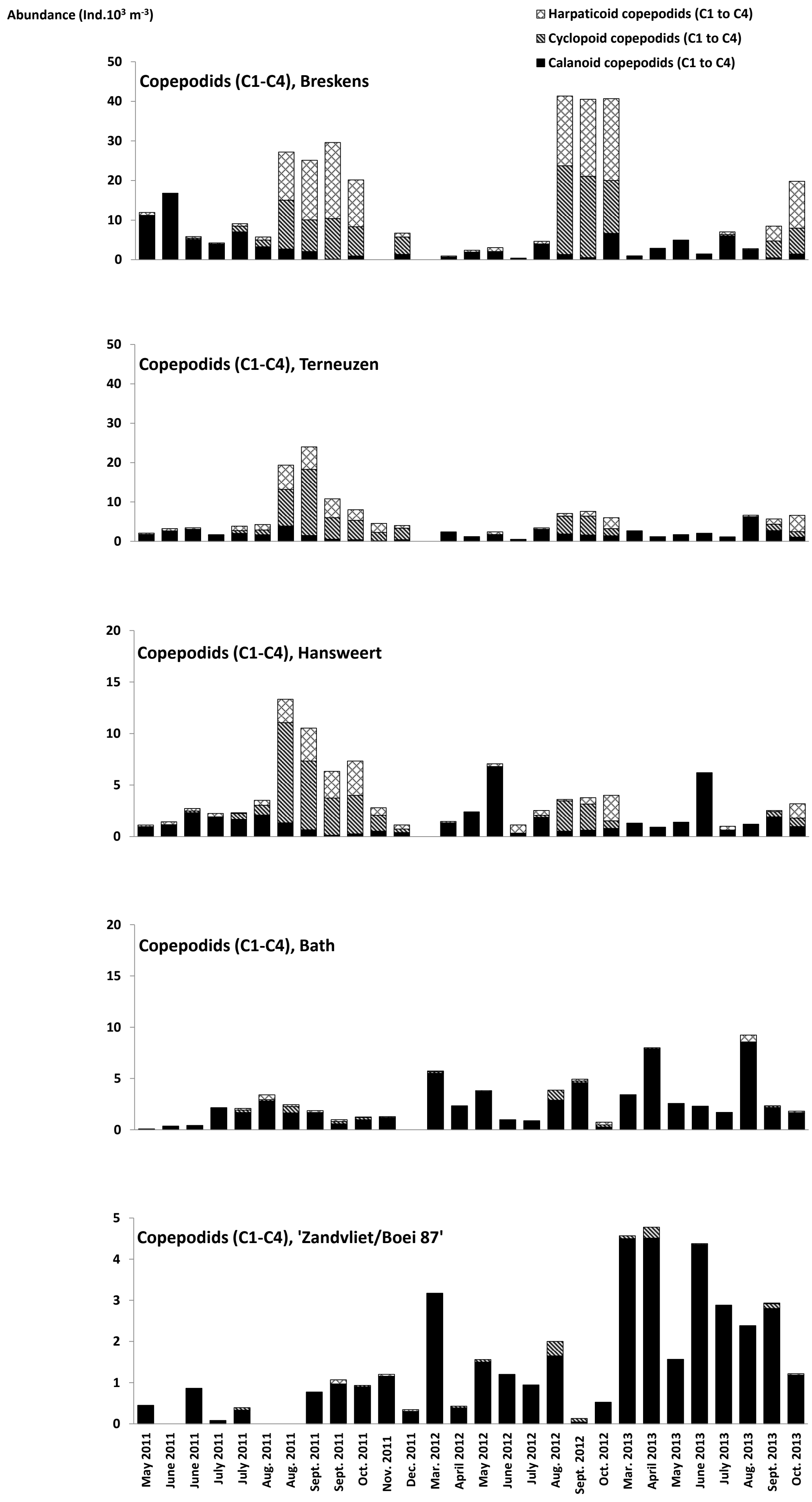


Fig. 3.2. Abundance of copepod copepodids (C1-C4) at each station observed twice a month between May and November 2011 and once a month between March and October in 2012

As to the young copepodid stages (C1-C4) of the copepods (Fig. 3.2), calanoids dominated at all stations during spring. Cyclopoids and harpacticoids were abundant from August till October for Breskens till Hansweert during 2011, and occurred in lower abundances during 2012 and 2013. At Bath and Zandvliet/Boei 87 calanoid copepodids dominated strongly and harpacticoids and cyclopoids were rare during all years. Calanoid copepodids were rare at station Bath during 2011, but became dominant during 2012 and 2013. At station Zandvliet/ Boei 87 calanoid copepodids were almost always dominant, showing peak abundance during spring 2012.

The abundance of C5 and adult copepods belonging to the different orders (Fig. 3.3) reached peak abundances during August-September at the stations Breskens, Terneuzen and Hansweert, but that abundance was lower during 2012 and 2013 than during 2011. These peak abundances are mainly due to harpacticoids and cyclopoids; calanoids at these stations being present at lower abundances mainly during spring. At Bath, an irregular pattern of abundance occured over time, with higher abundances during 2012 and 2013 than during 2011, mainly due to calanoids, while cyclopoids dominated strongly at this station in 2011. At Zandvliet/Boei 87 peaks of calanoids were observed in May-June during 2012, the remainder of the period being characterised by low abundance of adult/CV copepods, with sporadic occurrence of cyclopoids and harpacticoids.

The spatial trend observed in 2011 in the importance of the different orders was confirmed over the entire period; harpacticoids and cyclopoids dominated at the downstream stations Breskens, Terneuzen and Hansweert and calanoids dominated at the upstream station Zandvliet/Boei 87. At Bath, a variable pattern in the abundance of the different orders occurred: cyclopoids dominated in 2011; calanoids in 2012 and 2013. Over the entire Westerschelde, calanoid abundance varied (when present) from between 43 and 5 660 ind. m^{-3}. Cyclopoid abundance varied between 44 and 8 800 ind. m^{-3}. Harpacticoid abundance was between 33 and 8 000 ind. m^{-3}.

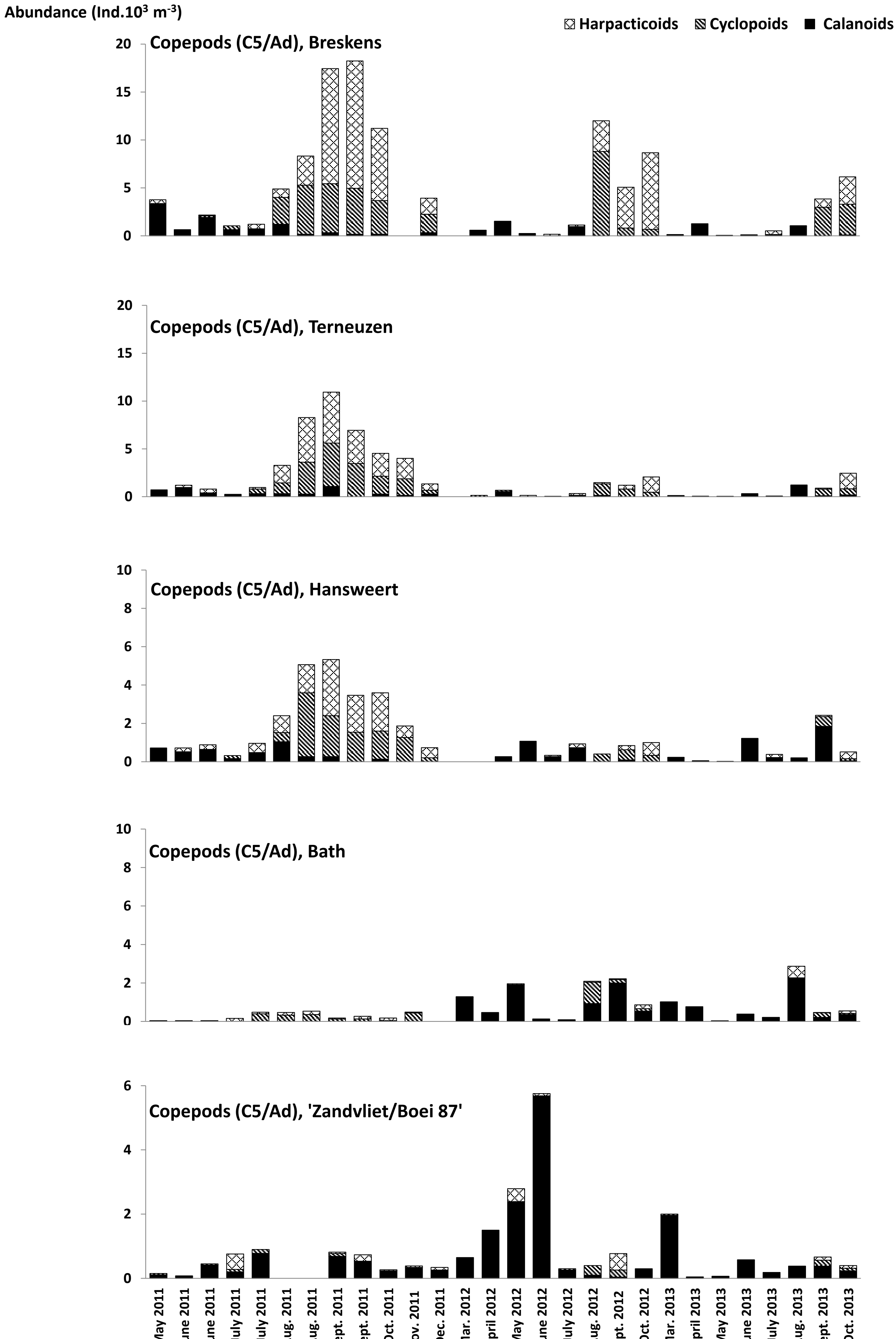


Fig. 3.3. Abundance of copepod adults and C5 showing different orders at each station observed twice a month between May and November 2013 and once a month between March and October in 2012 and 2013.

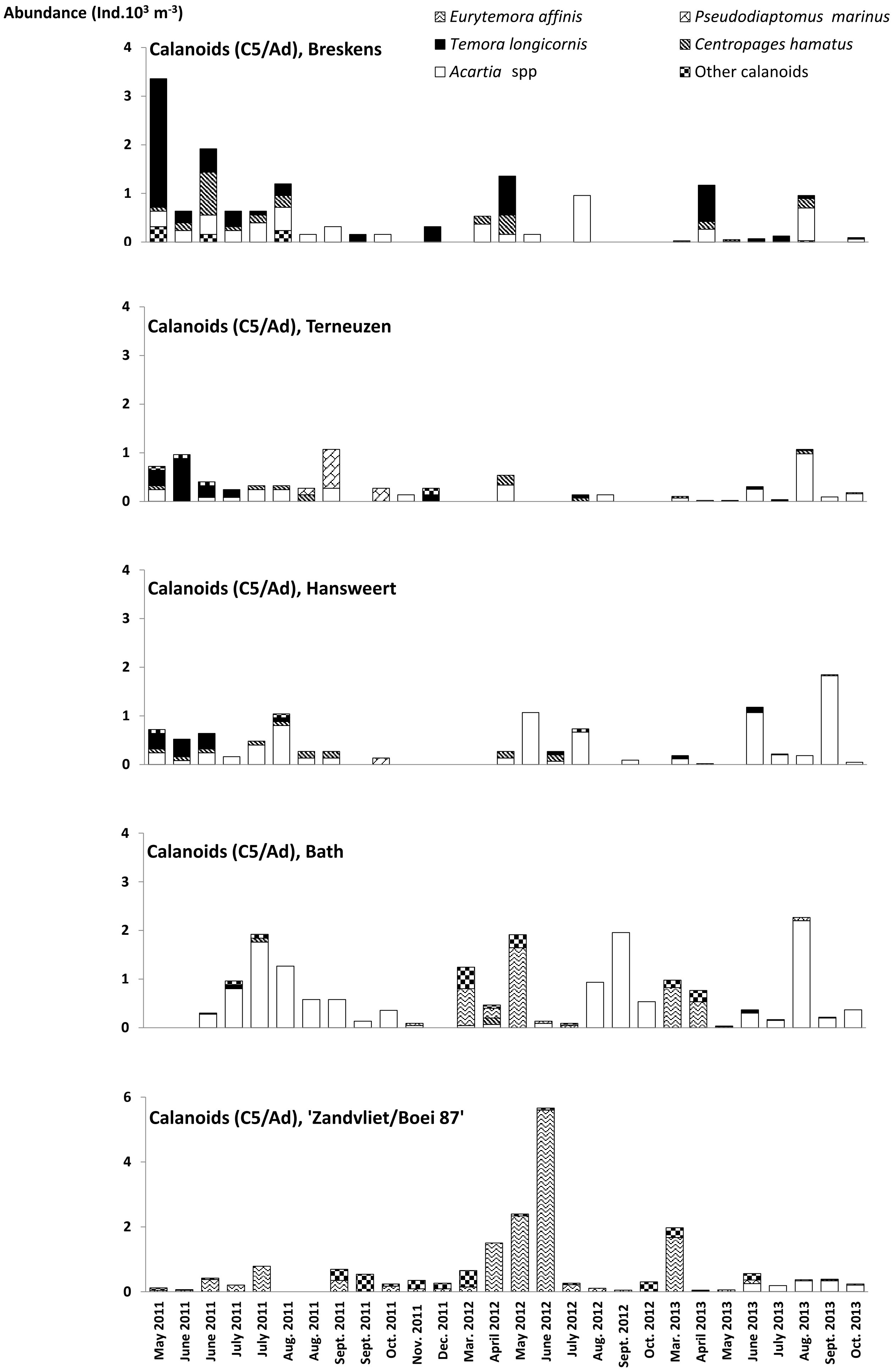


Fig.3.4. Species abundance within calanoid C5 and adult calanoid at each station observed twice a month between May and November 2011 and once a month between March and October in 2012 and 2013.

Adult and C5 calanoid abundance at the downstream stations Breskens and Terneuzen was lower during 2012 than during 2011, showing quasi complete absence of adult and C5 calanoids between May and October 2012. In 2013, abundance remained low, with occasional peaks in April and August (Fig 3.4). At the other stations, abundance during all years was comparable, except for a strong abundance in April-June at station Zandvliet/Boei 87. Within the calanoids, only *Acartia bifilosa, Centropages hamatus* and *Temora longicornis* were observed at stations Breskens and Terneuzen, whereas other calanoids were also present at these stations during 2011. *Temora longicornis* occured typically in spring at Breskens, Terneuzen and Hansweert, while *Acartia* spp. generally dominated at Hansweert and Bath. *Pseudocalanus marinus*, quite abundant at Terneuzen in August 2011, was not observed during 2012 or 2013. We notice an important abundance of *Eurytemora affinis* at Bath in spring 2012 and to a lesser extent in 2013. In the upstream station Zandvliet/Boei 87, *E. affinis* strongly dominated the adult/C5 calanoid community during April-June 2012 and March 2013.

At stations Breskens, Terneuzen and Hansweert, cyclopoid adult and C5 abundance was lower in 2012 and 2013 than observed during 2011 (Fig. 3.5). During 2012 and 2013, adult and C5 cyclopoids were quasi absent during spring at most stations, and their summer abundance at these stations was lower than during 2011, with the exception of a high peak in August 2012 at Breskens. At station Bath abundance was comparable over the years, with one peak during August 2012. Very low abundance of cyclopoids was observed at station Zandvliet/Boei 87.

During all years, cyclopoids were dominated at all stations by *Oithona brevicornis*, occurring from august onwards (Fig. 3.5). For the station Zandvliet/Boei 87, only total cyclopoids abundance is available for 2011 (data OMES), so no comparison is possible for Zandvliet/Boei 87. In 2012 and 2013 *Oithona brevicornis* appeared as the only cyclopoid species in all stations except for Bath and 'Zandvliet/Boei 87'.

Harpacticoid C5 and adult abundance was significantly lower during 2012 and 2013 than during 2011 at all stations (Fig. 3.6). *Euterpina acutifrons* was generally very dominant, other harpacticoids occurring mainly during spring at stations Breskens, Terneuzen and Hansweert, and more spread over time at Bath and Zandvliet/Boei 87.

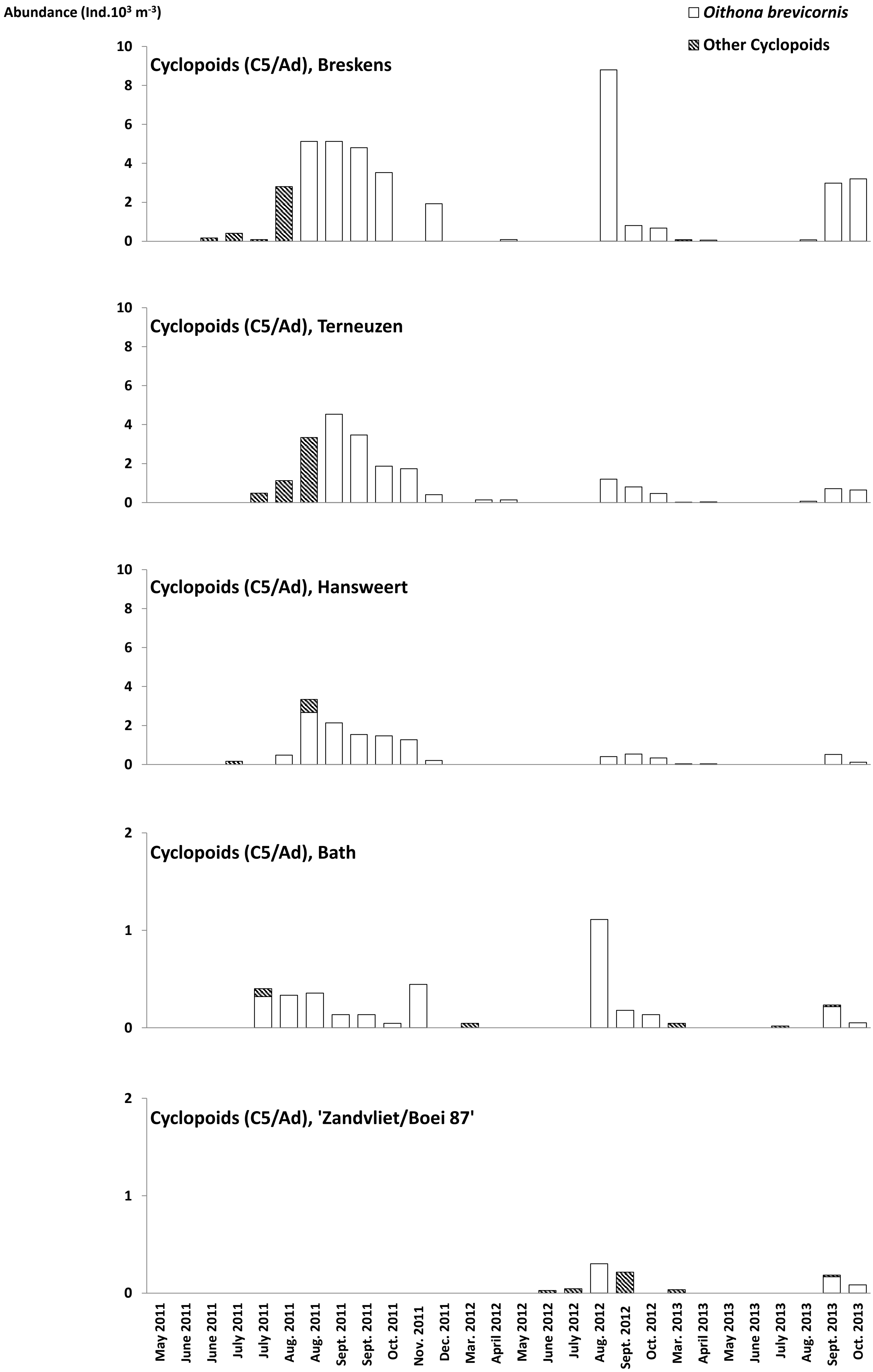


 Fig.3.5. Species abundance within C5 and adult cyclopoids at each station observed twice a month between May and November 2011 and once a month between March and October in 2012 and 2013.

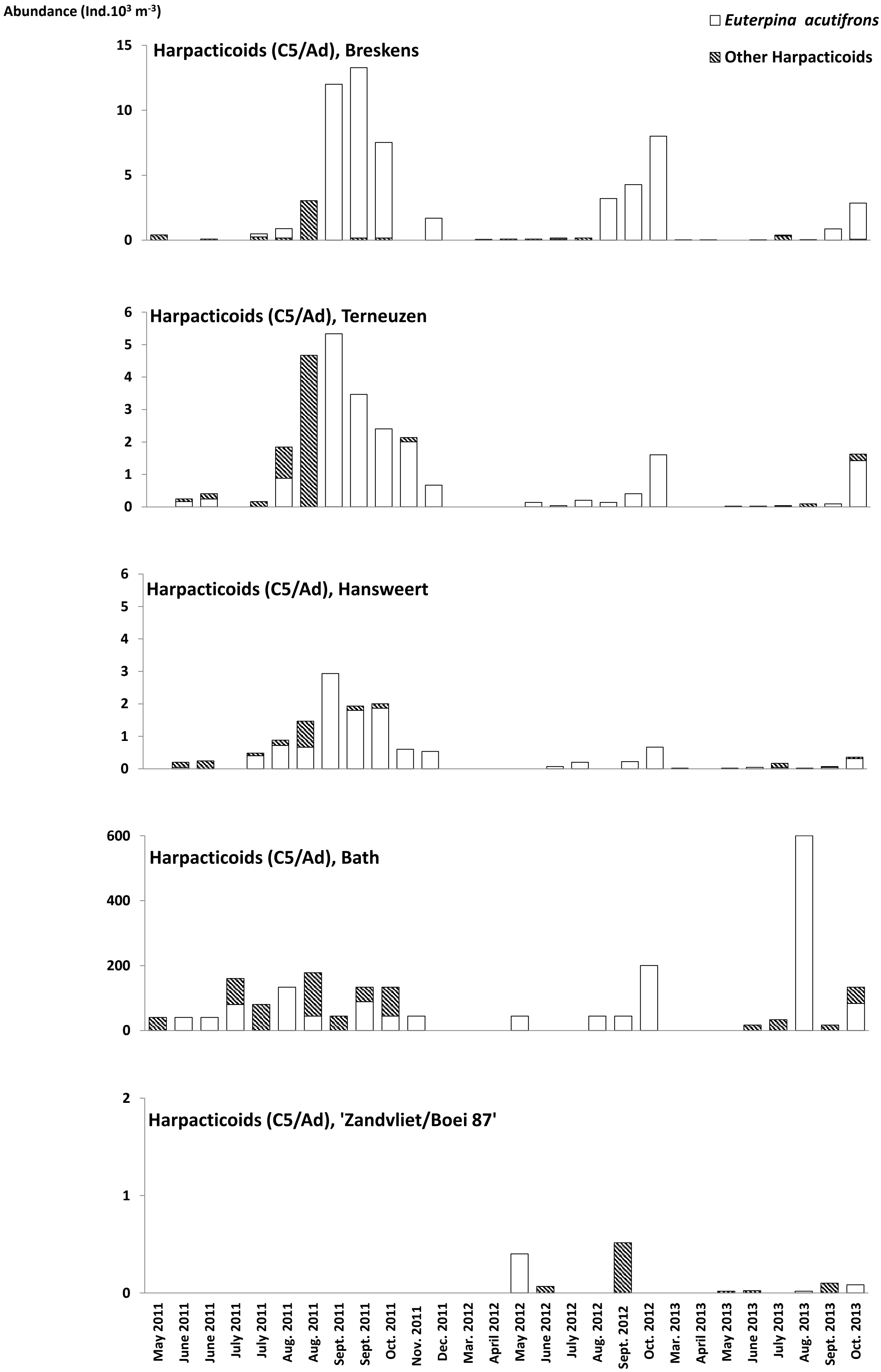


Fig. 3.6. Species abundance within C5 and adult harpacticoids at each station observed twice a month between May and November 2011. Only one sampling took place between May to October in 2012 and 2013.

3.3. Yearly mean abundance

To obtain a more concise view of the spatial zooplankton distribution, yearly mean abundance of each group was calculated for each station. These mean abundances are represented in Figs 3.7 - 3.11. The significance of spatial trends was tested by Spearman rank for the 2013 data (complete set of 5 stations MONEOS samples analysed) and the results are shown in Table 3.2.

Bivalve larvae, polychaete larvae, cyclopoid and harpacticoid adults and C5, and *Acartia* spp, *T. longicoris* and *C. hamatus* decreased significantly in abundance from downstream to upstream. *E. affinis* increased toward upstream. Within the copepod adults and VC5 stages, *E. affinis* shows a significant increase in abundance from downstream towards upstream, contrary to the other calanoids. This results in a non- significant change in abundance for the total group of calanoids.

*Table 3.2. Significance of decrease in abundance from downstream toward upstream for the different zooplankton groups/ taxa tested by Spearmann – rank. * =< 0.05; **: p< 0.01; ***p< 0.001. NS: not significant.*

Group		Group	
Meroplanktonic larvae	NS	Cyclopoid adults & C5	***
Copepod nauplii	NS	Harpacticoid adults & C5	*
Cirrided nauplii	NS	Copepod copepodids C1-C4	NS
Bivalve larvae	*	*E. affinis*	*
Polychaete larvae	*	*Acartia spp.*	*NS*
Calanoid adults & C5	NS	*T. longicornis*	*
		C. hamatus	*

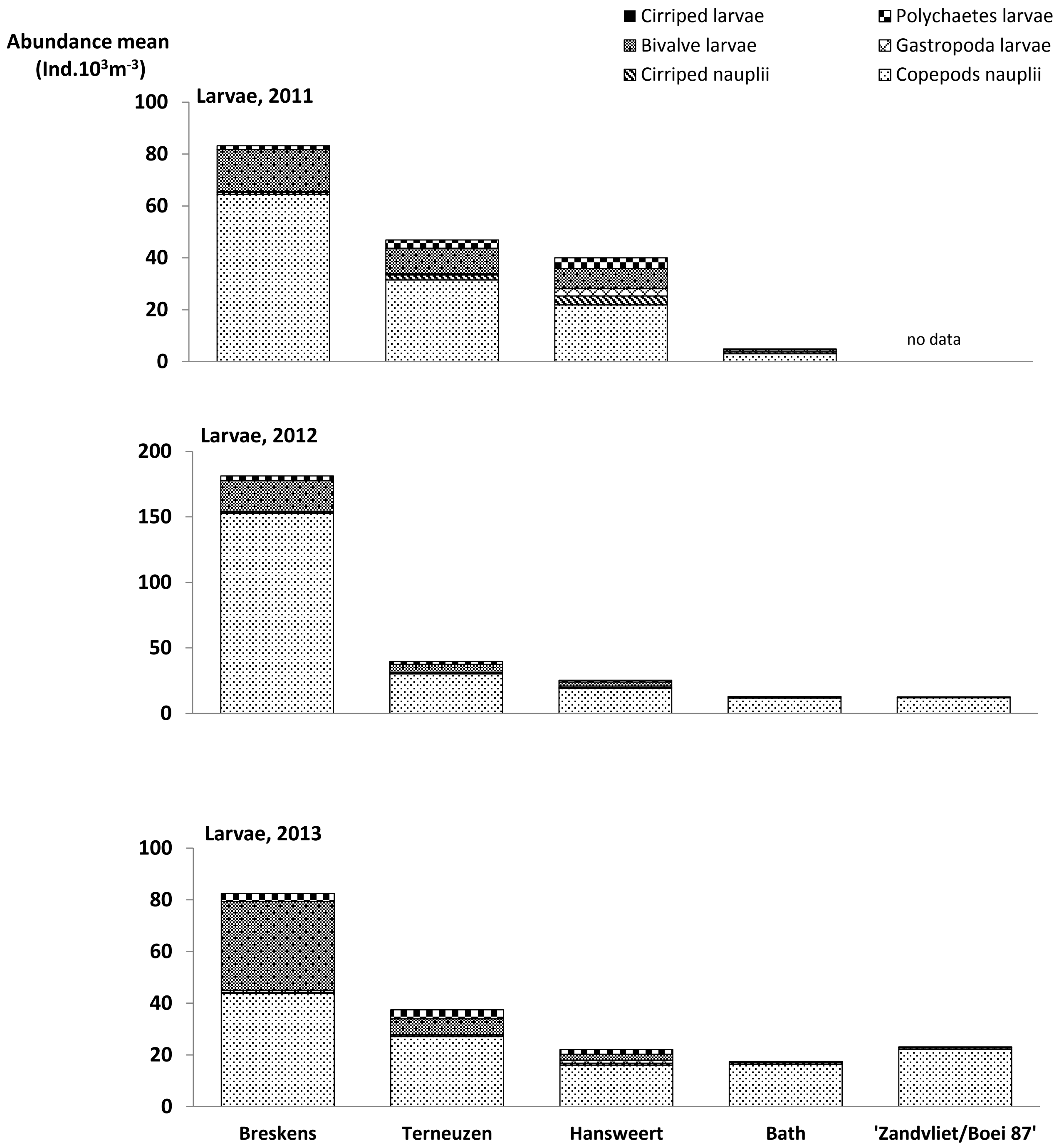


Fig. 3.7. Annual mean abundance of copepod nauplii and meroplanktonic larvae at each station for the 3 years studied.

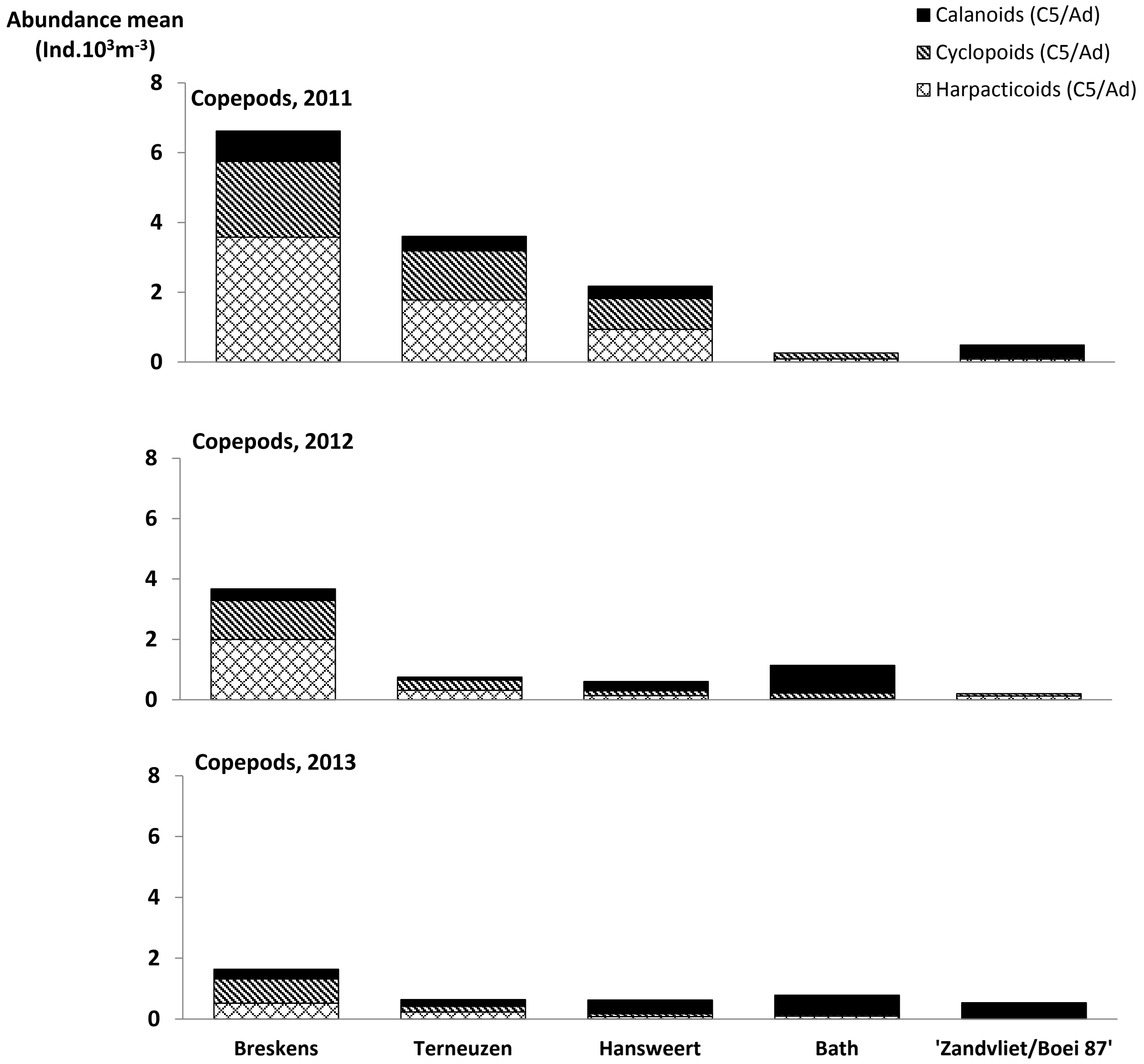


Fig. 3.8. Annual mean abundance of copepod adult and C5 showing different orders at each station for the 3 years studied.

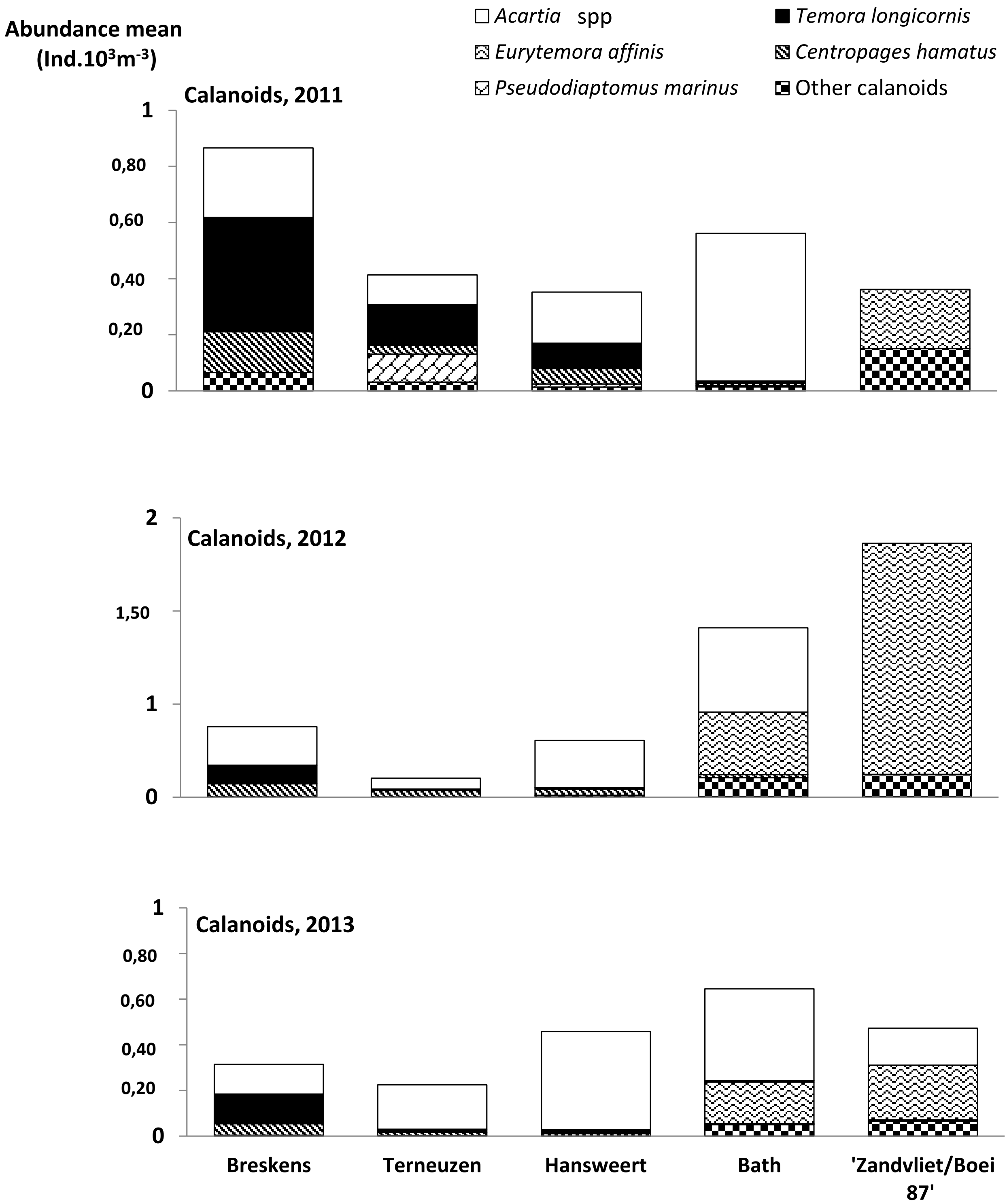


Fig. 3.9. Annual mean abundance of calanoid species adult and C5 at each station for the 3 years studied.

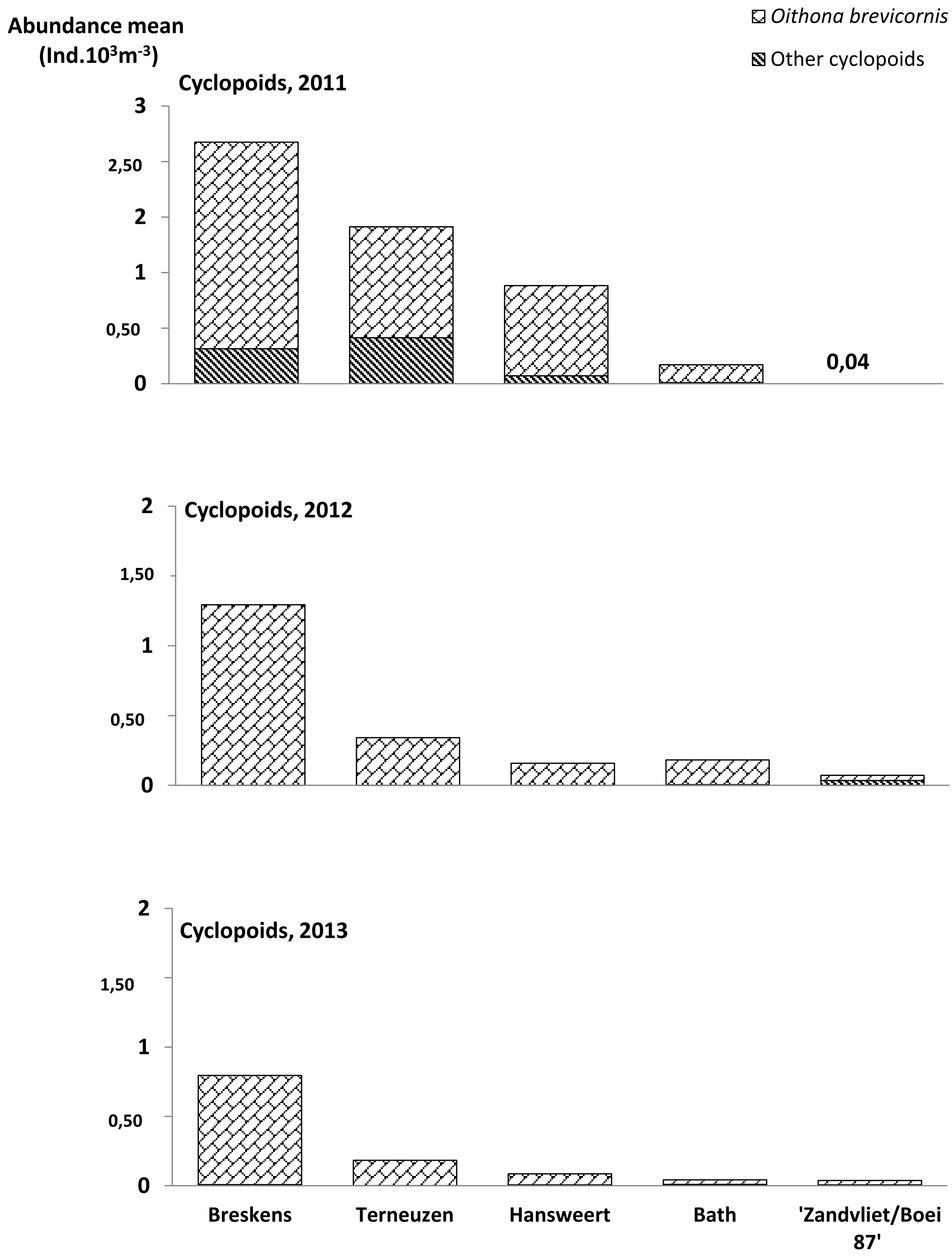


Fig. 3.10. Annual mean abundance of adult and C5 cyclopoids at each station for the 3 years studied.

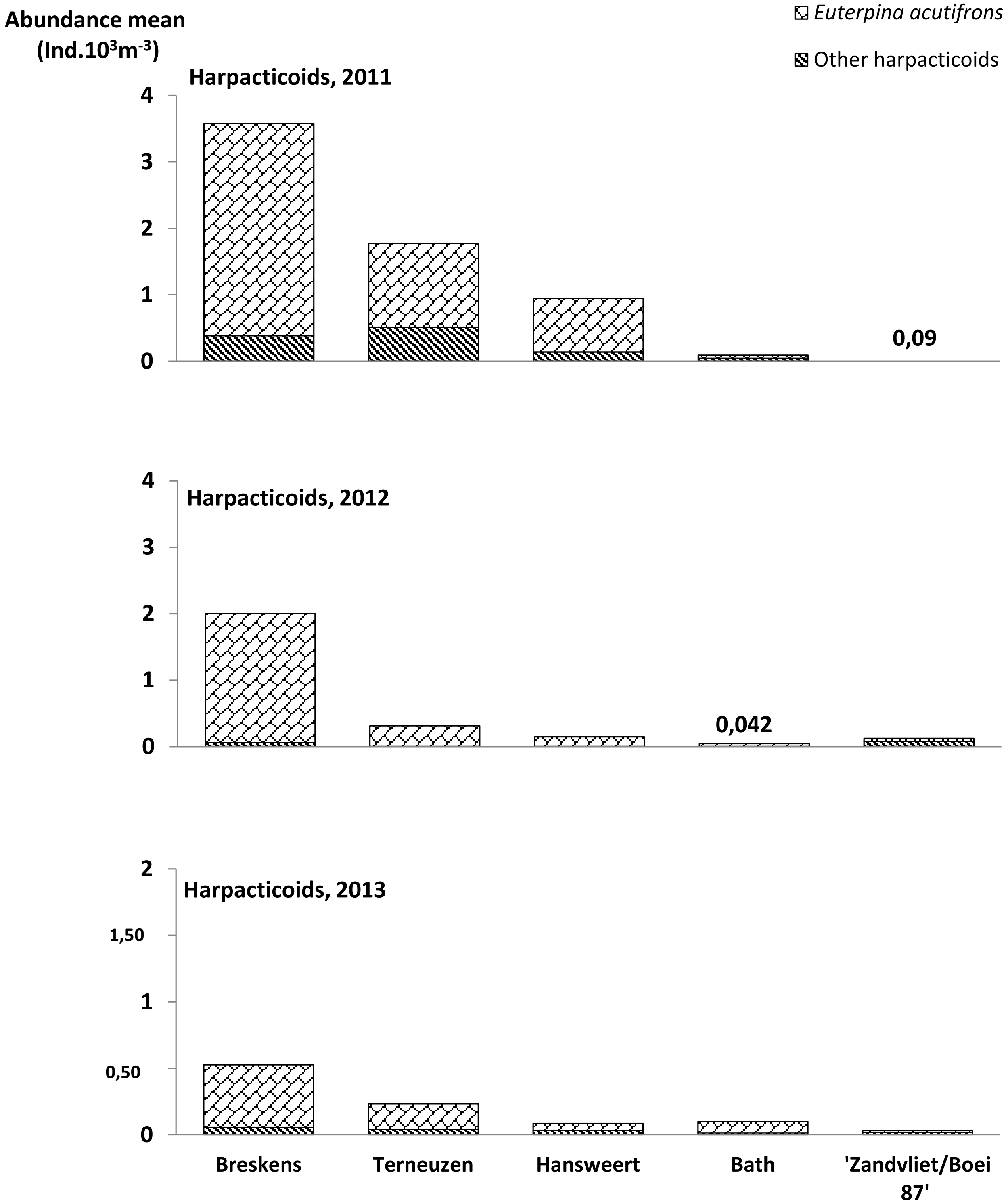


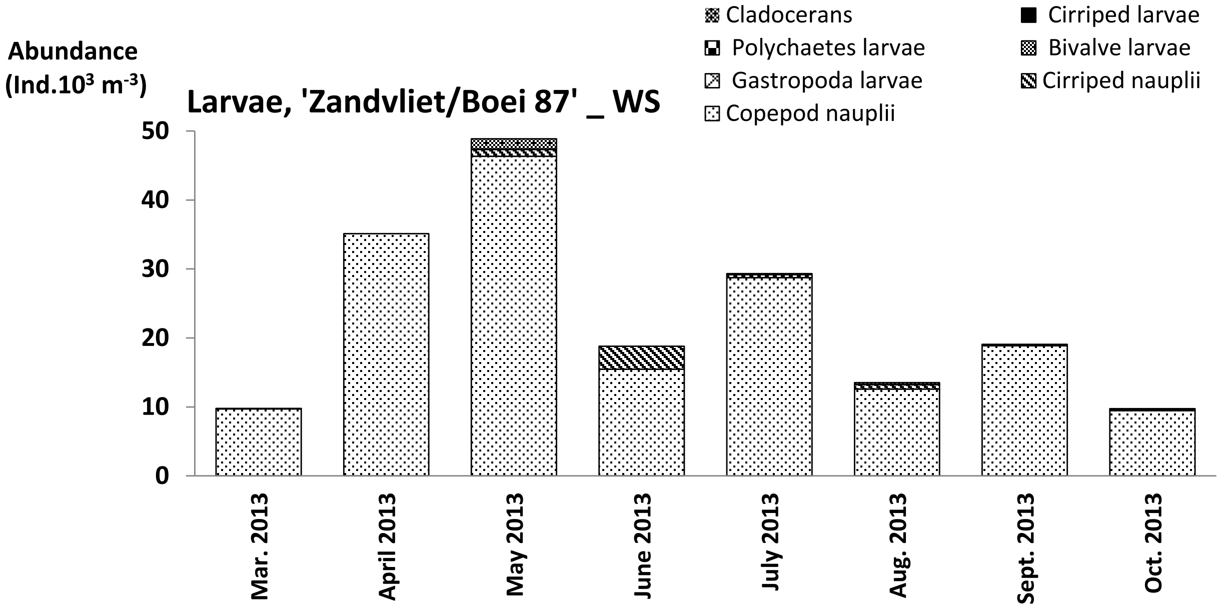
Fig. 3.11. Annual mean abundance of harpacticoids adult and C5 at each station for the 3 years studied.

3.4. Comparison of OMES and MONEOS sampling results

Because for 2011 and 2012; data from the station 'Boei 87' of the OMES samplings were used instead of the samples from station 'Zandvliet' of the Westerschelde campaigns, we analyzed 2013 Zandvliet samples and compared the resulting abundance values with 2013 OMES data of station Grens/Boei 87, considering the series March-August 2013. The results are presented in Figs 3.12-3.16. For each zooplankton group/ taxon considered, differences in abundance of the series consisting of all samples for 2013 were tested by sign test. The result of the test showed that, abundance of copepod nauplii and copepodites were significantly lower for the OMES 'Boei 87' than for the MONEOS Zandvliet WS' sampling. All other groups and taxa considered were found to be not significantly different in abundance between the two sampling techniques (Table 3.3).

Table 3.3. Result of statistical testing (sign test) of the abundance results obtained for station Zandvliet (MONEOS) and Grens/Boei 87 (OMES).

Variables	Nb.non ex-aequo	% v<V	z	valeur p
WS_cala & OMES_cala	6	66,66667	0,408248	0,683091
WS_cyclo & OMES_cyclo	3	66,66667	0,000000	1,000000
WS_harpac & OMES_harpac	4	50,00000	-0,500000	0,617075
WS_Cop & OMES_Cop	6	66,66667	0,408248	0,683091
WS_copepodids & OMES_copepodids	6	0,00	2,041241	0,041227
WS_Cop nauplii & OMES_Cop nauplii	6	0,00	2,041241	0,041227
WS_Cirr nauplii & OMES_Cirr nauplii	5	20,00000	0,894427	0,371093
WS_Gast. & OMES_Gast.	3	33,33333	0,000000	1,000000
WS_Bivalv & OMES_Bivalv	3	0,00	1,154701	0,248213
WS_Polych & OMES_Polych	3	33,33333	0,000000	1,000000



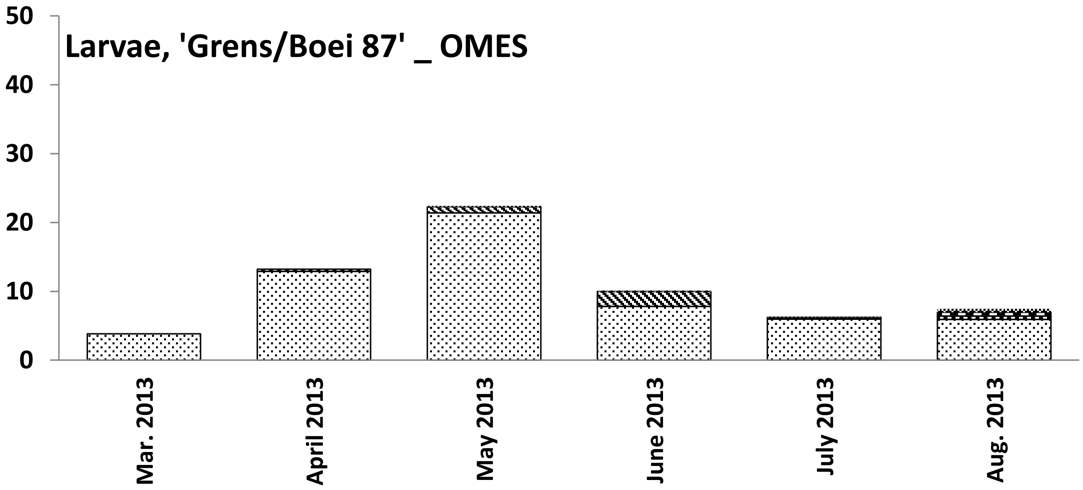
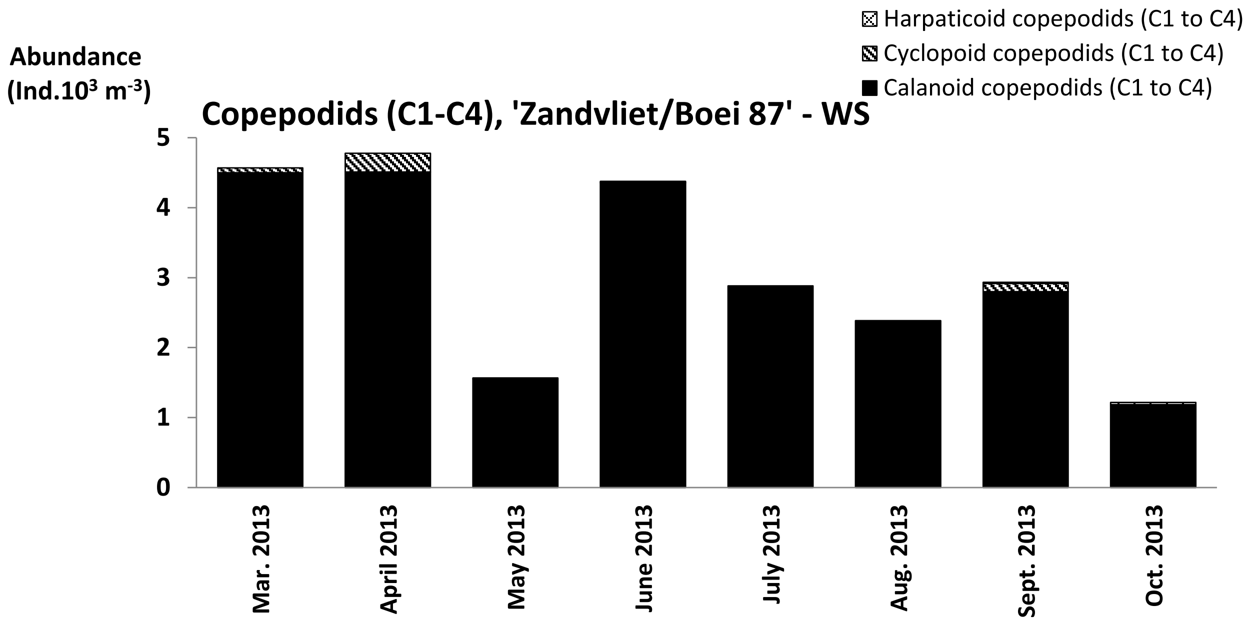


Fig. 3.12. Abundance of copepod nauplii and meroplanktonic larvae observed at Zandvliet for Westerschelde (WS) and at Boei 87 OMES project in 2013.



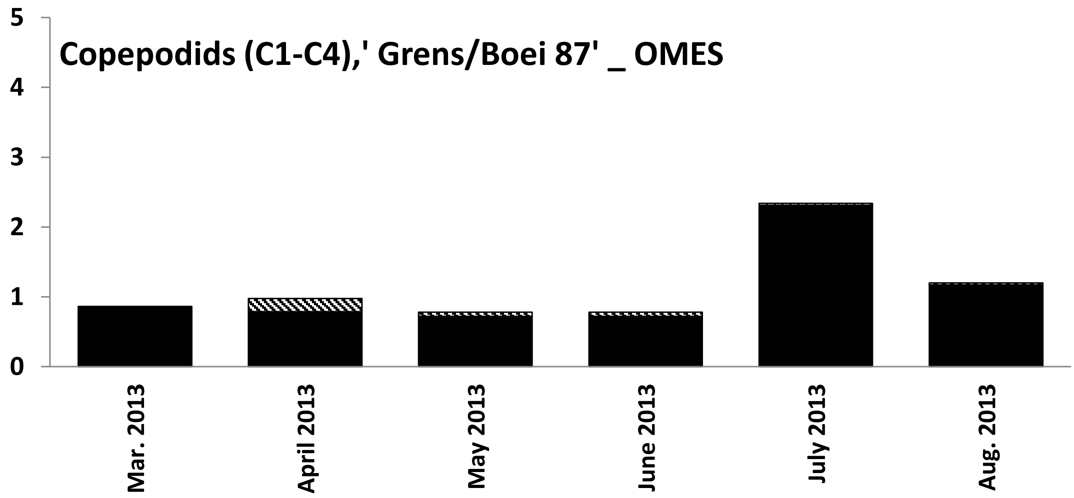
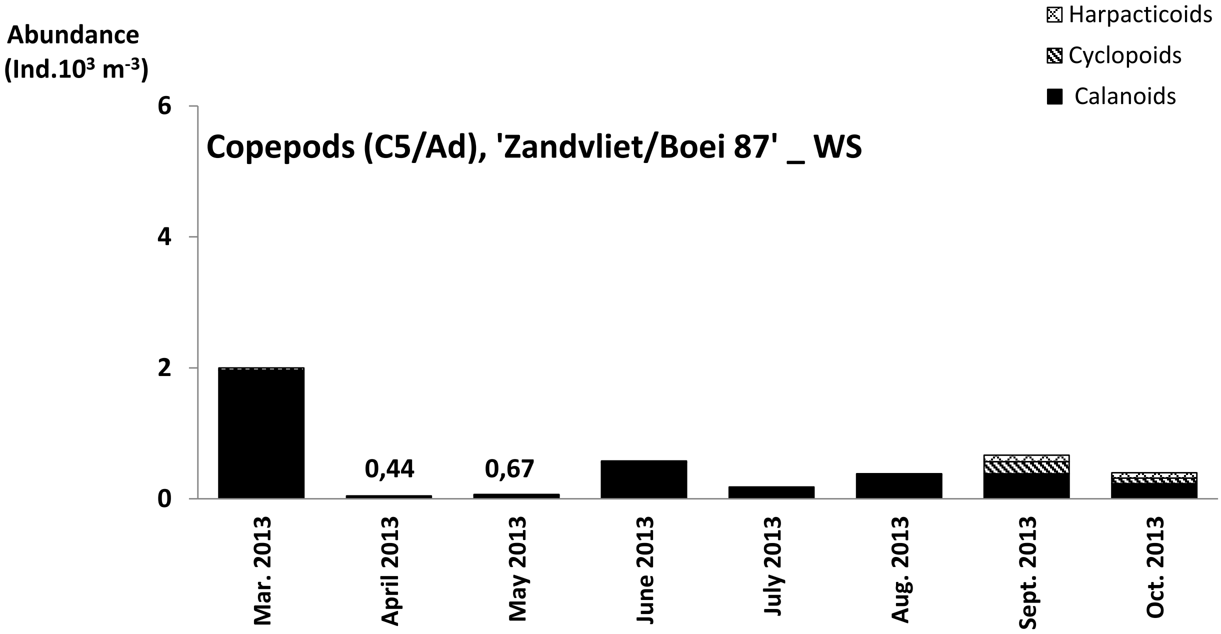


Fig. 3.13. Abundance of copepodid copepods observed at Zandvliet for Westerschelde (WS) and at Boei 87 OMES project in 2013.



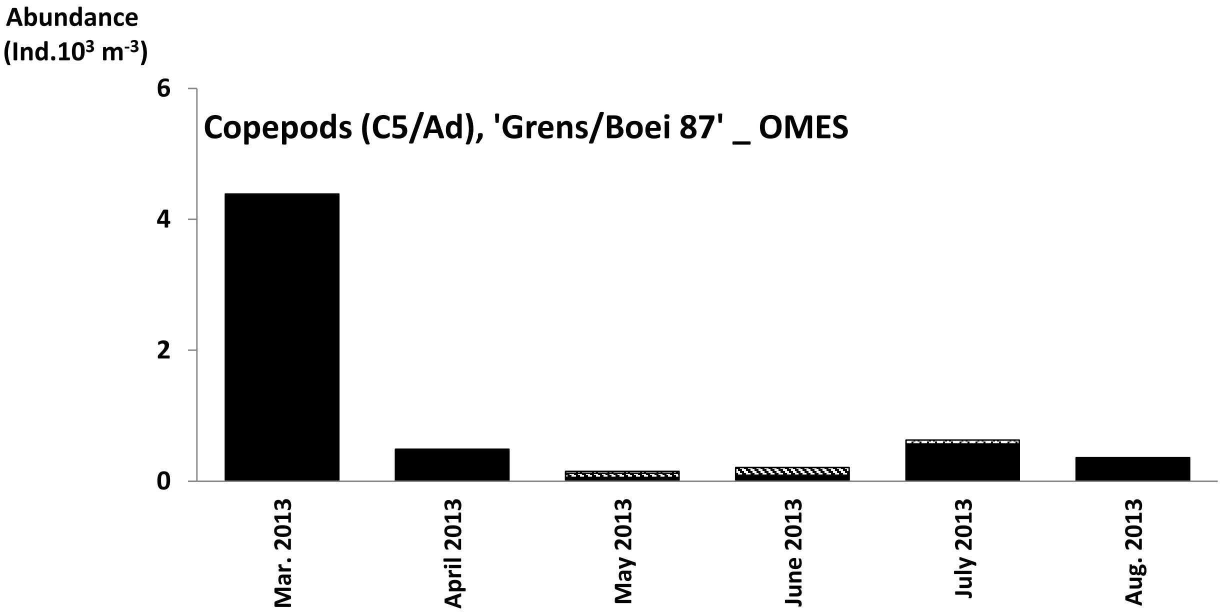
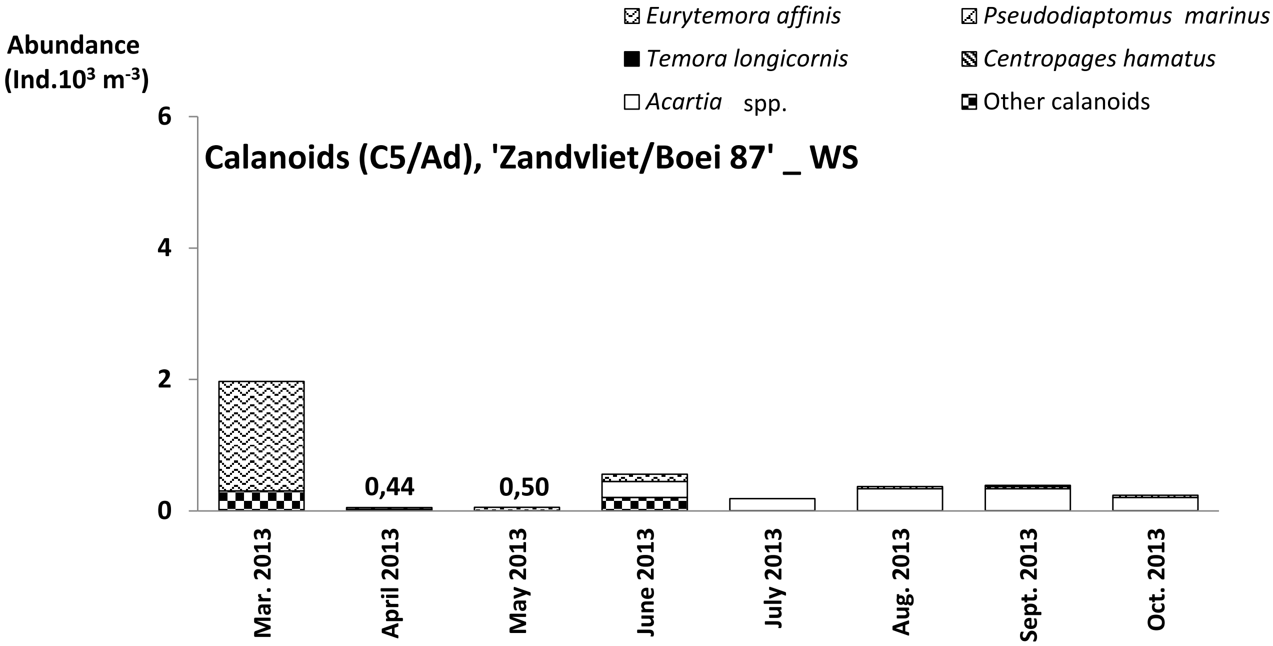
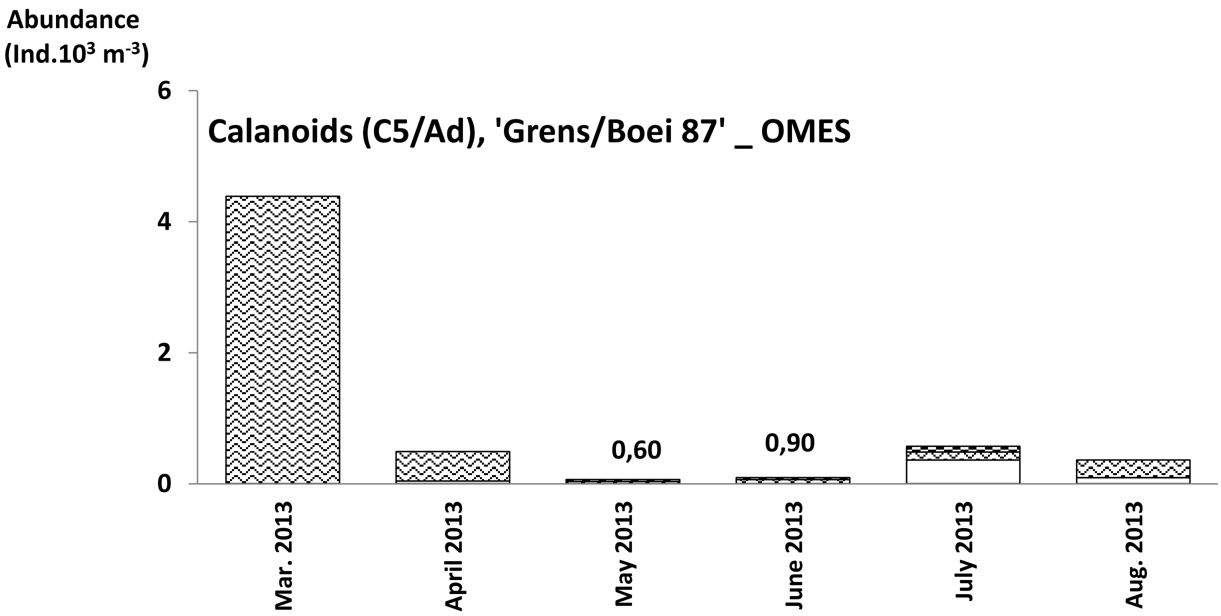
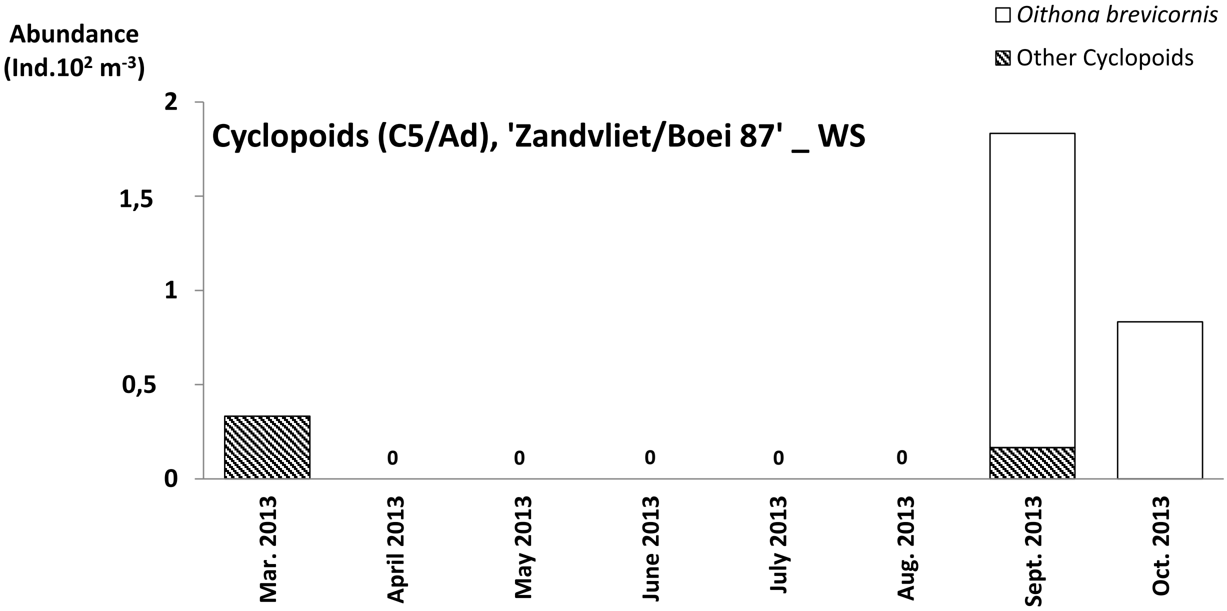


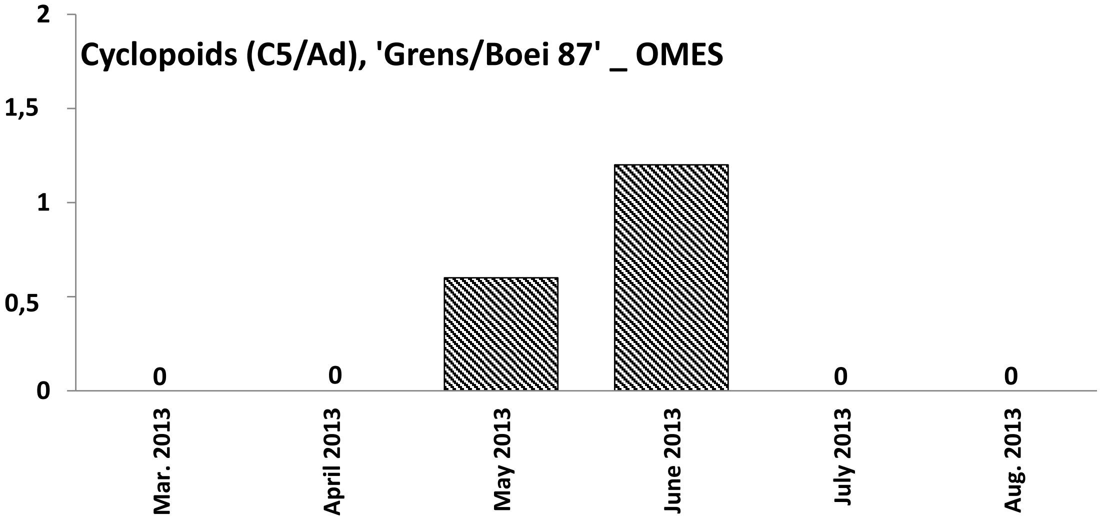
Fig. 3.14. Annual mean abundance of adult and C5 copepods showing different orders observed at Zandvliet for Westerschelde (WS) and at Boei 87 OMES project in 2013.



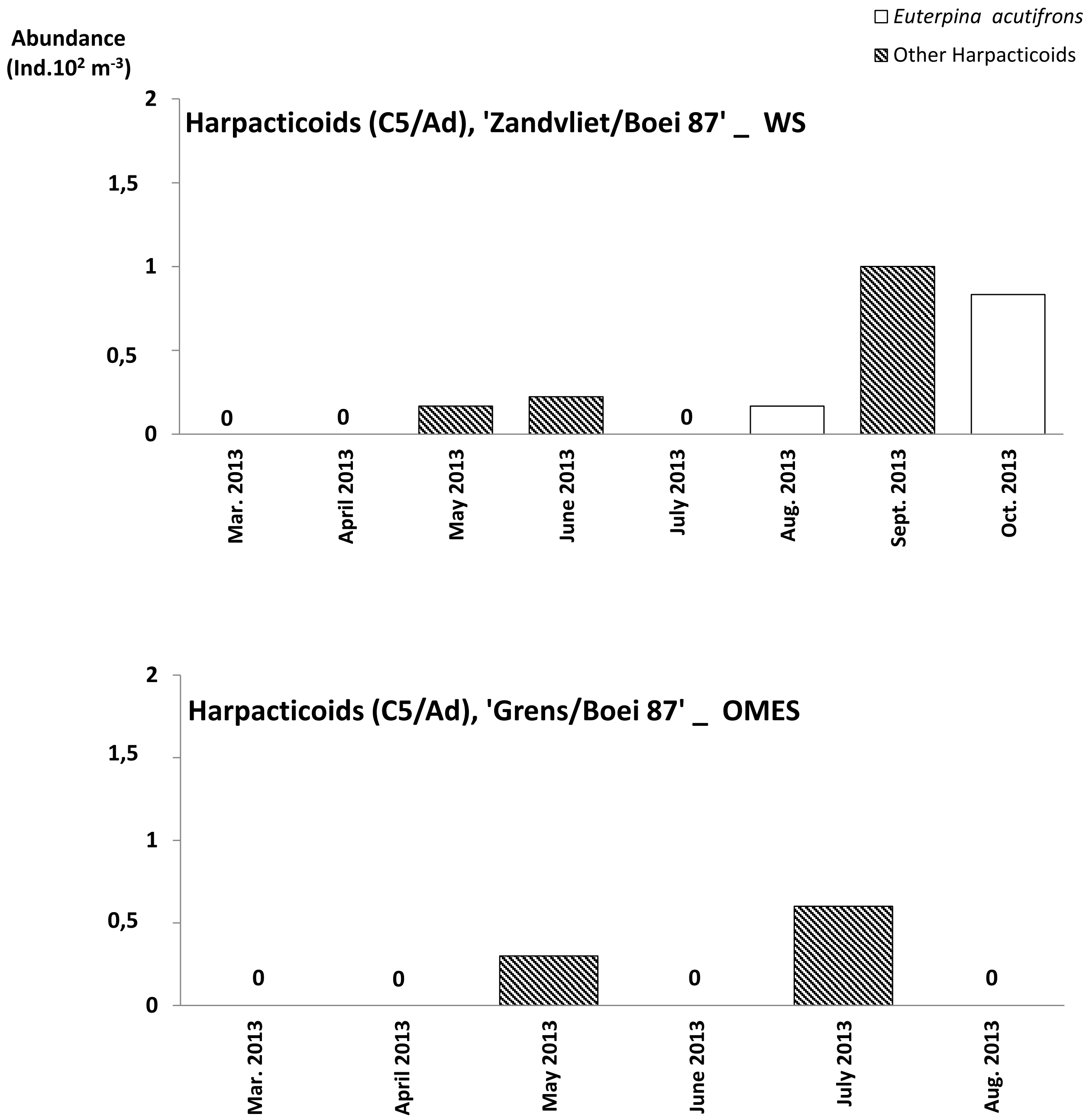


3.15. Annual mean species abundance within calanoid C5 and adult copepods observed at Zandvliet for Westerschelde (WS) and at Boei 87 OMES project in 2013.





3.16. Annual mean species abundance within cyclopoids adult and C5 copepods observed at Zandvliet for Westerschelde (WS) and at Boei 87 OMES project in 2013.



3.17. Annual mean species abundance within adult and C5 harpacticoids observed at Zandvliet for Westerschelde (WS) and at Boei 87 OMES project in 2013.

3.4. Zooplankton spatio-temporal distribution in the entire Schelde estuary.

Fig. 3.18 shows, for all years, the spatio-temporal distribution of the three orders of copepods over the Schelde estuary from Vlissingen (0 km from the mouth) up till Melle (155 km from the mouth), as compiled from this study and OMES data.

The 2013 OMES data are not yet available, but considering that the 2013 data in the Westerschelde, are in the same order of magnitude as those of 2011 and 2012, this compilation confirms the much lower abundance of calanoids and cyclopoids in the downstream Westerschelde than in the upstream Zeeschelde. While calanoids show low abundance up till km 85, followed by an increase and high abundance peaks in upstream direction from km 85 onwards, cyclopoids show a more bimodal spatial distribution, with considerable abundance downstream, up till km 49, followed by a quasi-void between km 58 and 121, and considerable abundance from km 125 and upstream.

Harpacticoida are more abundant in the Westerschelde than in the Zeeschelde.

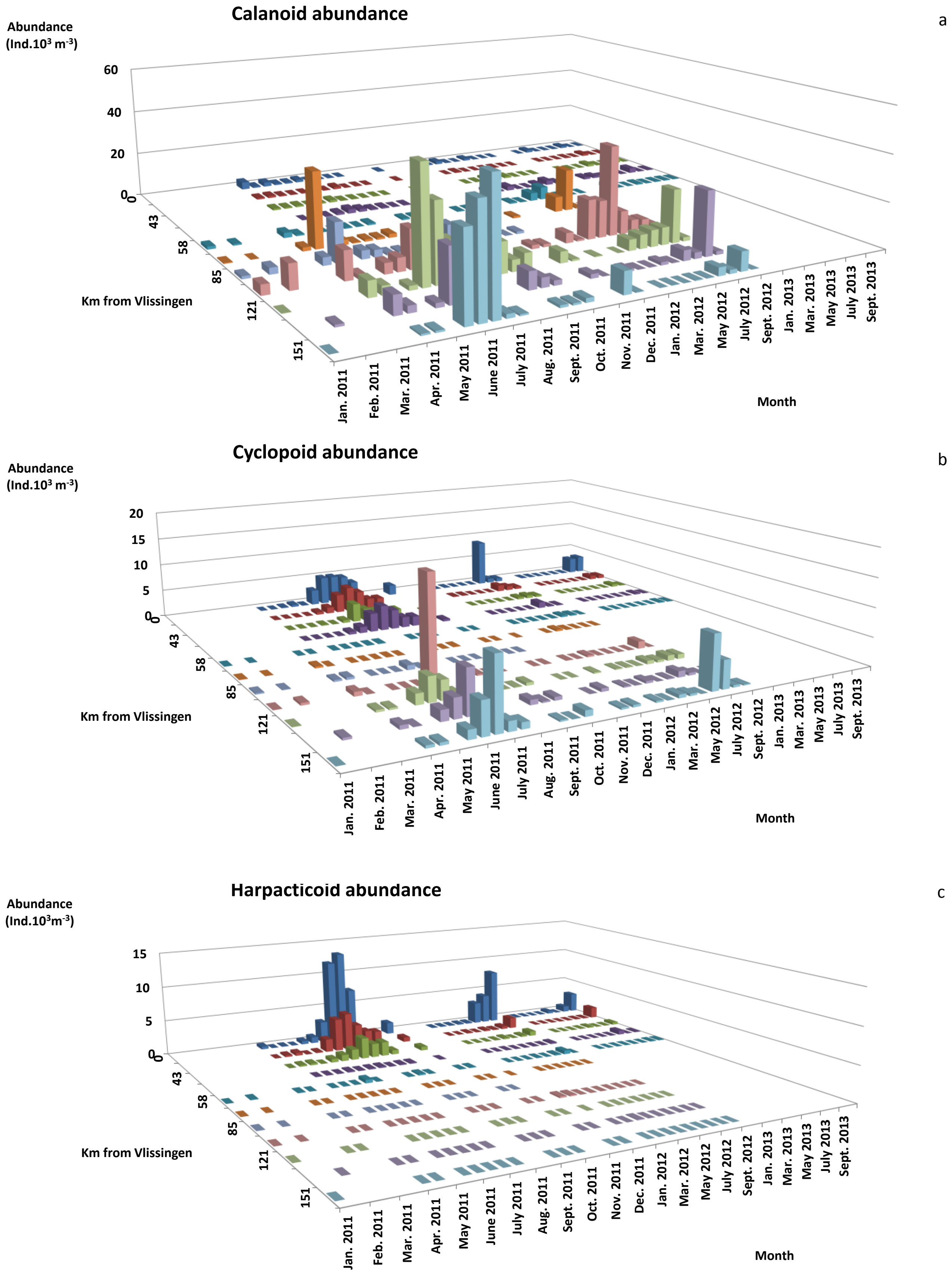


Fig. 3.18. Monthly mean abundance of a) calanoids, b) cyclopoids and c) harpacticoids in the total Schelde estuary, as compiled from this project and 2011-2012 OMES data. The stations are represented as a function of their distance to the mouth of the Schelde at Vlissingen (in km).

3.3 Relating species to environmental data

Multivariate analysis were performed on the combined data of 2011, 2012 and 2013 for stations Breskens, Terneuzen, Hansweert, Bath and Zandvliet/Boei 87. To improve comparability between years, environmental data of NIOZ were used in all cases, contrary to previous reports (Tackx et al., 2012, 2013) which used data provided by Rijkswaterstaat. The modality of the taxa distribution was first analyzed by a Detrended Correspondence Analysis (DCA), using Detrending by segments. As the total inertia observed (1.0) was always less than 2.6, a predominance of linear species response curves could be expected, and so we used redundancy analysis (RDA), a technique in which the ordination axes are constrained to be linear combinations of provided environmental variables to investigate the relationships between environmental factors and taxa composition. Data were log transformed prior to analysis.

In the following, species – environmental and station – environmental biplots are shown for the combined dataset of the 3 years of observations. The analysis performed for each year separately are given in Annex 1.

As can be seen from Fig 3.19 and Table 3.4, the mesozooplankton species distribution in the Westerschelde is related to the salinity gradient associated with increasing Secchi depth (lower left corner), as opposed to increasing concentrations of SPM, POC and nutrients (upper right corner). The oxygen, Chl *a* and Phaeo-pigments vectors are positioned in between these two tendencies (lower richt corner). Remarkable is the association of NH_4 and O_2 in this positioning.

Taxa found associated with the salinity vector, found in the left below corner of the biplot, (including red ellipse) concern larvae and typical marine taxa like the calanoid copepods *Temora longicornis* and *Centropages hamatus*, and the cladocerans *Evadne* and *Podon*. At upper right corner of the biplot, *Eurytemora affinis* and other calanoids are associated with NO_3. Generalised groups such as copepod nauplii and other cyclopoids are close to the origin of the ordination (green ellipse). The groups within the bleu ellipse concern mainly cyclopoids and harpacticoids, associated with salinity and temperature. It is remarkable that no taxa are strongly associates with Chla, Pheaopigment and oxygen concentration.

Fig 3.20 shows the grouping of data per station, illustrating the decreasing salinity gradient from Breskens till Zandvliet/ Boei 87. This graph also shows a considerable overlap between the stations.

Fig 3. 21 represent the variation in time of the zooplankton ordination during the three years. The three years almost completely overlap, few extremes during 2012 corresponding to the nutrient vectors.

Table 3.4. Results of RDA analysis performed on combined 3-years data

Axes	1	2	3	4	Total inertia
Eigenvalues:	0.142	0.088	0.032	0.022	1.238
Species-environment correlations:	0.749	0.786	0.576	0.681	
Cumulative percentage variance					
of species data:	11.4	18.5	21.1	22.8	
of species-environment relation:	41.6	67.3	76.6	83.1	
Sum of all eigenvalues					1.238
Sum of all canonical eigenvalues					0.341

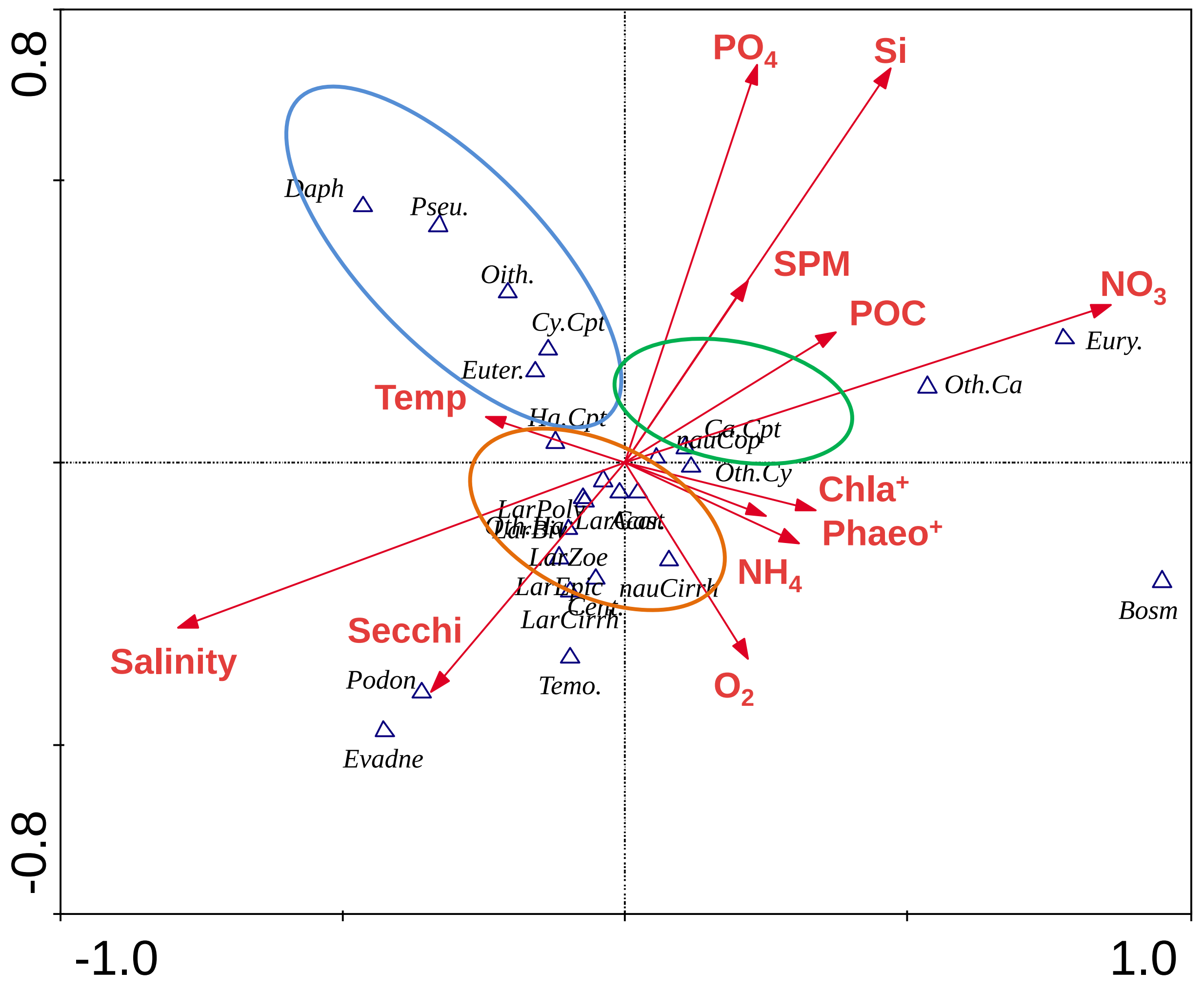


Fig 3.19. Species and environmental factor ordination of 3 years compiled abundance data. Axes 1 and 2

Table 3.5. Contents of each ellipse of 3-years data

Blue ellipse	Green ellipse	Orange ellipse
Daphnia	Calanoid copepodids	Polychaetes larvae
Pseudodiaptomus	Copepod nauplii	Gastropoda larvae
Oithona	Other cyclopoids	*Acartia* spp.
Copepodids cyclopoid		Other harpacticoid
Euterpina		Bivalve larvae
Copepodids harpacticoid		Zoe larvae
		Epicarids larvae
		Cirriped nauplii
		Centropages
		Cirriped larvae

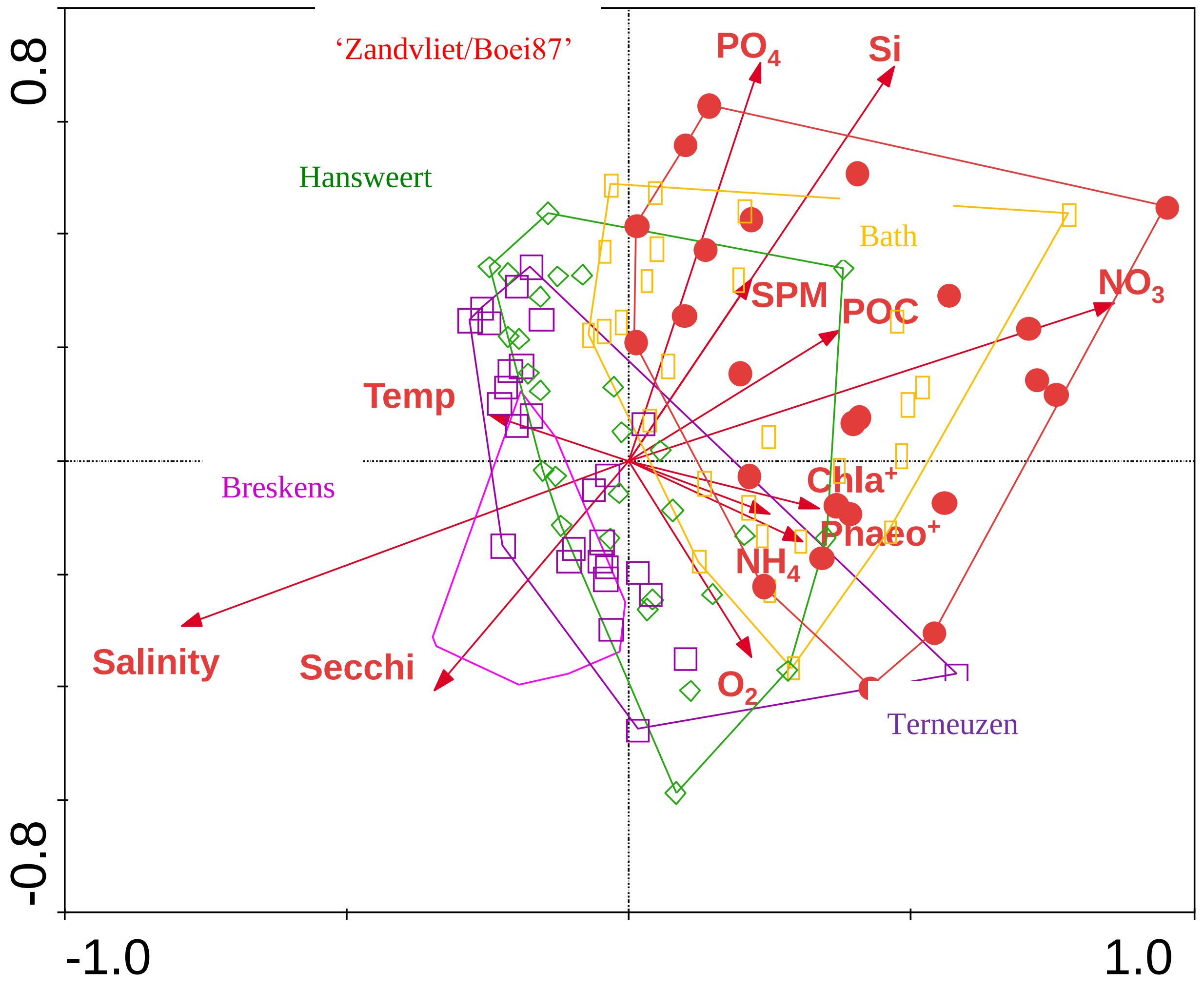


Fig 3.20. Biplot (axes 1 and 2) showing the grouping of the samples for 3-years per station based on their biotic and abiotic characteristics.

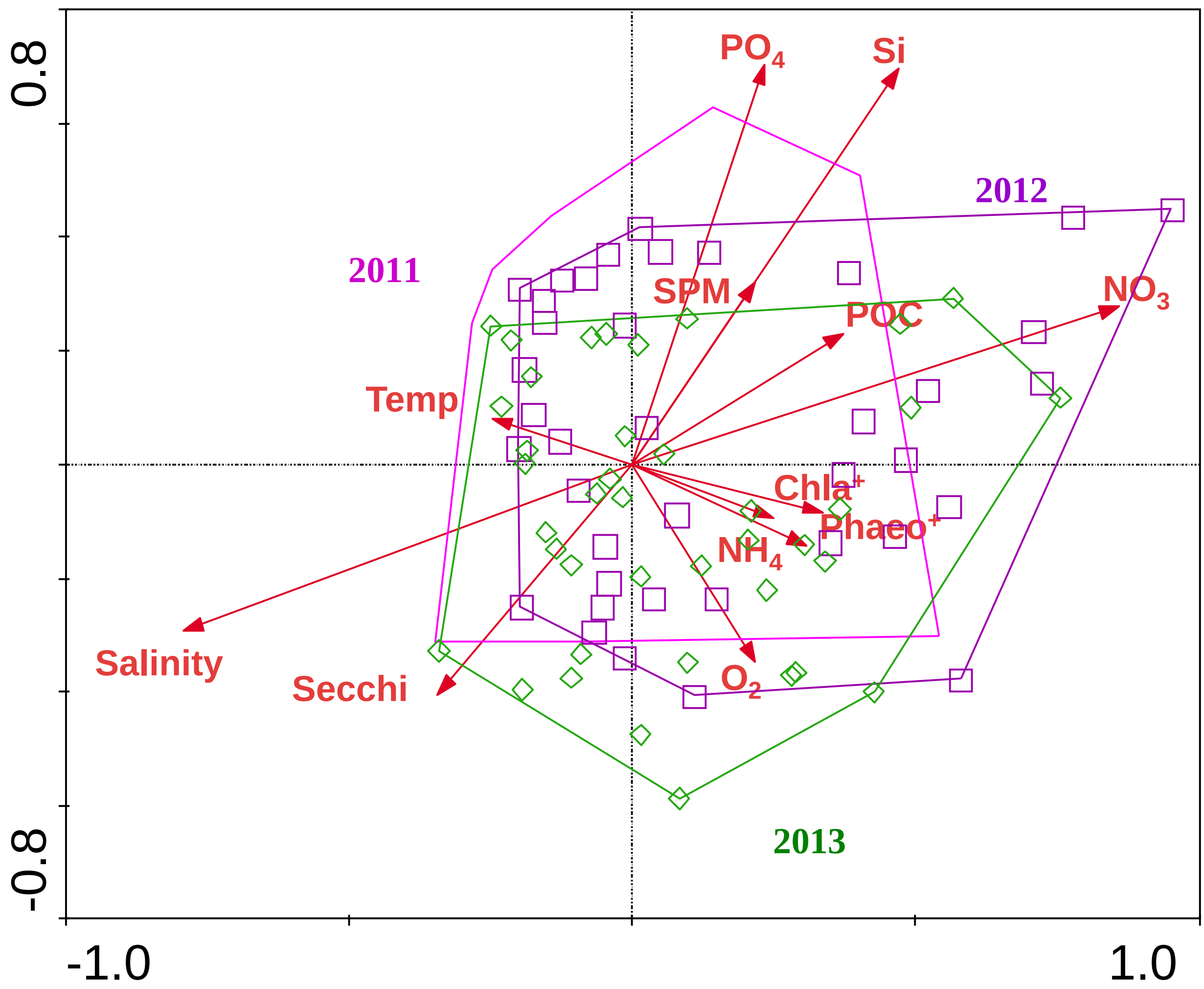


Fig. 3.21. Biplot (axes 1 and 2) showing the grouping of the samples per year based on their biotic and abiotic characteristics.

4. Discussion

Three years of observing mesozooplankton abundance and composition at 5 stations in the Westerschelde provide a rather consistent view on the spatio-temporal distribution of the mesozooplankton community within the Westerschelde. We hence concentrate, in this report, mainly of general trends rather than on detailed descriptions of taxa abundance at each station.

Over the entire Westerschelde, mesozooplankton diversity is low showing a maximum of 6-7 taxa present at one station. The 2013 observations did not reveal any other taxa then 2011 and 2012. This paucity was already reported by reported by Soetaert & Van Rijswijk (1993) and in previous reports (Tackx et al., 2012; 2013). It should be kept in mind however, that within the scope of this study, it was not possible to determine each group at a high taxonomic resolution. Larvae, abundant downstream, are very difficult to determine at species or even genus level. For cyclopoids and harpacticoids, the community was most of the time very strongly dominated by one species (*Oithona* *brevicornis* and *Euterpina acutifrons* respectively) but our analysis did not allow to precise the taxa composition of the 'other' groups.

While the abundance and relative importance of all identified taxa of copepod nauplii, meroplanktonic larvae and C1-C5 stages of copepods remained in the same order of magnitude at all stations and years, or at least no systematic differences (= at all stations) were observed between years, there seemed to be a tendency for adults and C5 calanoids to be less abundant at the downstream stations during 2012 and 2013 than during 2011. During 2012 and 2013, many (quasi) 'zero' observations occur, which was not the case during 2011. Considering the natural variability within the mesozooplankton community and the fact that sampling in 2011 only started in May, while the March-October period was considered for 2012 and 2013, this tendency requires deeper analysis. The upstream stations showed more comparable abundances of all orders and stages of copepods during all years. For calanoids, a clear peak of *E. affinis* was occurring in spring at Bath and Zandvliet/Boei 87 in 2012 and, to a lesser extent, in 2013. We suggested in our 2011 report that the curious absence of this species in the 2011 might have been due to the fact that sampling in 2011 only started in May (Tackx et al., 2012). This species is of interest because it has been shown to 'shift' its maximum abundance zone upstream toward the freshwater in parallel to the water quality improvement taking place in the Zeeschelde (see further). While we observed the potential invasive species *Pseudodiaptomus marinus* in 2011, it was absent from the 2012 and 2013 Westerschelde samples.

Plotting yearly average abundance of groups/taxa per station for the entire sampling transect illustrates a clear decrease in abundance from downstream towards upstream for several taxa. The fact that typical larvae of saltwater organisms, such as bivalves and polychaetes s well as the typical North sea calanoids *T. longicornis* and *C. hamatu*s adult and C5 stages decrease in abundance in upstream direction is normal. That no significant trend is found for copepod nauplii, and *Acartia* spp. is probably due to the grouping of several species within this group. As mentioned before, Acartia spp. is dominated by the marine species A. *clausi*, but also *A. tonsa*, a more brackish water species was occasionally observed. Adults and C5 *E. affinis* showed an increase in abundance towards upstream is not surprising, as it is a typical brackish-freshwater species complex. *E. affinis* was very abundant around the 10-12 salinity range of the Scheldt during the 1990ties (Soetaert & Van Rijswijk (1993), Sautour & Castel (1995), but has shifted its peak abundance from the brackish water reach towards the freshwater reach in parallel to the Schelde water quality improvement (Appeltans et al.,2003; Mialet et al., 2010; 2011). As we now have data on the entire salinity range, it would be possible to investigate if *E.affinis* abundance has changed in the brackish water area also, by comparing in detail with these previous studies. This comparison will be however somewhat complicated by the fact that Soetaert & Van Rijswijk (1993) have distinguished 'adults and big copepods', versus small copepodids, while we have distinguished 'adult and C5' and C1-C4 copepodids, the latter par order, not per species. So a realistic comparison would require some further determination of the copepodid 1-4 stages. This could be restricted to stations Bath and Zandvliet, as Soetaert & Van Rijswijk (2003) show that *E. affinis* was absent from the more downstream stations during 1989-1991.

It should be noticed from fig 3.19, that only few taxa are strongly associated with particular environmental conditions, such as, for example, *Evadne* and *Podon* with salinity, *Eurytemora* and other calanoids with freshwater or *Daphnia*, *Pseudocalanus* and *Oithona* with temperature. The majority of the taxa are situated rather close to the origin of the ordination. This can be explained on the one hand by the low level of taxonomic determination, grouping, for example all copepod nauplii and C1-4 stages per order and on the other hand by the overlapping environmental conditions between the stations shown in Fig 3.20. The remarkable low association of zooplankton distribution with chl *a*, phaeopigment and oxygen concentration deserves further attention, as it coincides with the above mentioned- also remarkable- association of O2 and NH4.

The compilation of the data obtained within the Westerschelde – MONEOS frame with zooplankton OMES data on the upstream, Zeeschelde traject, allows to illustrate spatio-temporal distribution of zooplankton during recent years over the entire estuary. The picture arising from this exercise illustrates a bimodal distribution of the zooplankton community within the estuary. Calanoids are much more abundant upstream than downstream, cyclopoids are present in more comparable abundance downstream and upstream, and harpacticoids are much more abundant downstream than upstream. In between these two zone (roughly between km 43 and 121 from the mouth, very little zooplankton occurs. This area, which can be considered to correspond to the estuarine low diversity zone (Remane, 1971) deserves particular attention, as it offers possibilities to study the adaptability of different species to varying environmental conditions, imposed by the tidal and seasonal fluctuations. The Remane concept has recently been reviewed and criticized (Whitfield et al., 2012) as being too strictly based on benthic organisms. It would be interesting to analyze the Schelde zooplankton distribution - considering the entire estuary- within this framework.

In this regard, it seemed worthwhile to compare abundance results obtained by the different sampling strategy used in the Western Schelde and the OMES campaigns: a pump is used in the Westerschelde, while bucket sampling is done during OMES campaigns. The verification of the difference in performance of the different sampling techniques used in MONEOS and in OMES showed that, with the exception of copepod nauplii and copepodids C1-4, the abundance results obtained were not significantly different. This is encouraging for further comparison of results over the entire estuary. We also notice that, at some occasions, *E. affinis* abundance obtained by OMES sampling is higher than for MONEOS pump sampling. This phenomenon has already been observed by Toumi (unpublished data) who also reported higher abundance for *E. affinis* in the Zeeschelde when sampled at surface with a bucket than at surface with a pump. A possible explanation is that this copepod has a higher tactile sensitivity than others, allowing it to escape the suction of the pump. The fact that copepods, and especially calanoids, are shown to be much more abundant upstream (sampled by OMES technique) than downstream (sampled by MONEOS technique) strength then the picture of the bimodal mesozooplancton distribution in the Schelde.

Finally, a comparison was made between zooplankton abundance during Soetaert & Van Rijswijk's 1989-1991 observations and the present study. This was only done for calanoids, cyclopoids and harpacticoids, taking adults and all copepodid stages into account. Periods considered were April October 1989, March-October 1990 and March 1991 for the 1989-'91 period, and March-October 2012 and March-October 2013. Stations Vlissingen/Breskens, Ellewoutsdijk/Terneuzen, Hansweert/Hansweert and Bath/Bath were considered. As shown in Table 4.1, the obtained abundance ratio between the present and the past period is 0,44 for calanoids, 7,05 for cyclopoids and 1,3 for harpacticoids. When tested by monthly means over the considered periods for each station, no significant differences in abundance occur between the 1989-1991 observations and this study. A more thorough comparison, including other taxa and more stations and the environmental conditions during both periods would be worthwhile in order to evaluate these impressions.

Table 4. 1. Comparison of zooplankton abundance observed in the Westerschelde during 1989-'91 (data Soetaert & Van Rijswijk) and this study for calanoid, cyclopoid and harpacticoid copepods.

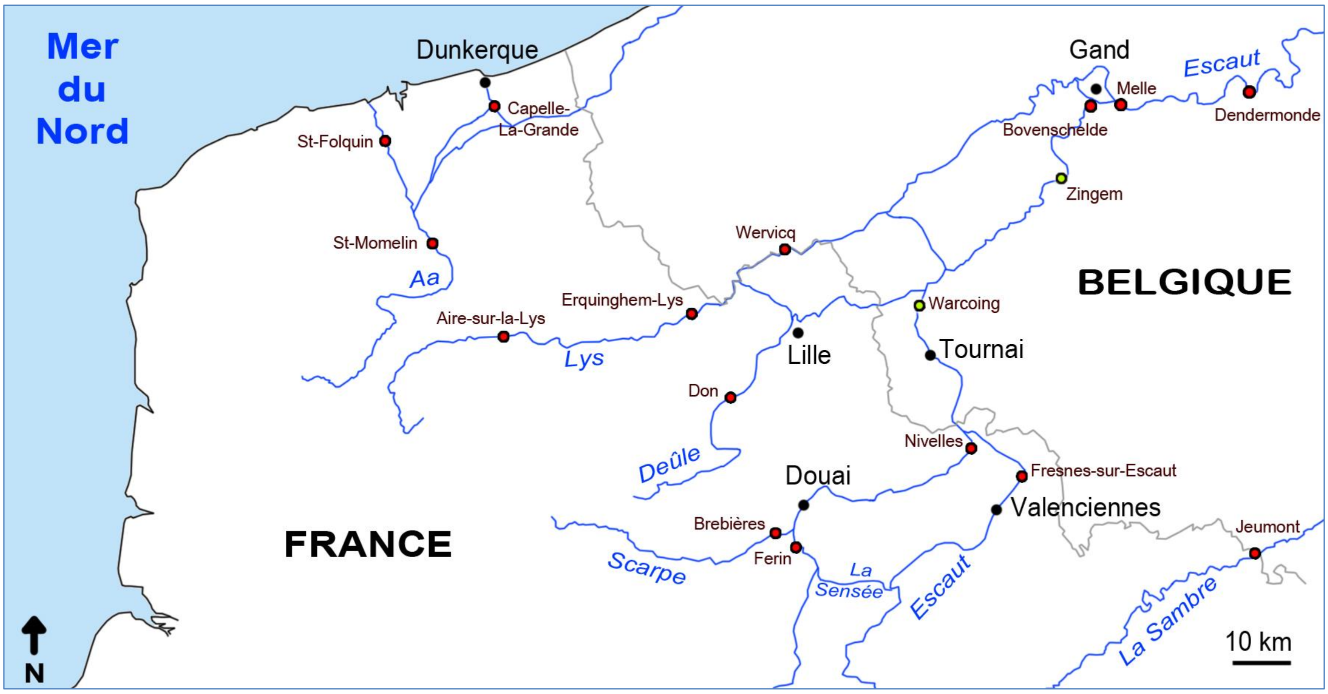
1989-1991 2012-2013		*VLISSINGEN* BRESKENS	*ELLEWOUTSDIJK* TERNEUZEN	*HANSWEERT* HANSWEERT	*BATH* BATH	*MEAN WS*	***Ratio*** ***2012-13 / 1989-91***
1989-1991 2012-2013	Calanoida	4582 **2796**	3323 **2141**	2781 **2184**	13625 **3680**	6078±4995 2700±716	**0.44±0.22**

1989-1991	Cyclopoida	557	117	33	85	198±69	**7.05±6.76**
2012-2013		**3544**	**1169**	**616**	**249**	1395±521	
1989-1991	Harpacticoida	2256	1518	959	534	1317±432	**1.30±0.88**
2012-2013		**5096**	**1021**	**549**	**163**	1707±665	

Combination of Westerschelde and Zeeschelde data clearly shows the existence of two different communities, with a low abundance-low diversity zone in between km 57 and km 121 from Vlissingen. Hummel at al. (1988) have postulated the existence of a coastal, primary production driven zone and a more detritus fueled brackish water zone within the Westerschelde. Within MONEOS, it will be of interest to perform more detailed analysis of the environmental conditions taxa distribution once the 2013 data are available over the entire transect Westerschelde-Zeeschelde. The transition area between the two communities is of interest to evaluate the spatio-temporal variability of the zooplankton species and hence the adaptability and tolerance of different taxa in this ‘high stress’ zone. It would be interesting to use the combined MONEOS-OMES data as a test case in the ongoing discussion about the diversity minimum (Whitfield et al., 2012). It would also be interesting to evaluate potential zooplankton grazing pressure on phytoplankton, taking into account important shifts in chl *a* concentrations which have been shown to occur both in the Zeeschelde and in the Westerschelde (Cox et al., 2009; Kromkamp & Van Engeland, 2010).

In a wider perspective, we draw attention to the fact that recently, the zooplankton community in the Schelde watershed is studied in the frame of the ‘BIOFOZI’ project (BIOdiversité et FOnctionnalité du Zooplancton : test du potentiel Indicateur de la qualité de l’Eau). This prohect, financed by the Nord pas de Calais region, the Fondation pour la recherche sur la Biodiversité and the Agence de l’eau Artois Picardie (AEAP) inventorises zooplankton taxonomical composition and abundance over a continuum between the river Scheldt on Frensch territory and the strerupwards staions of the OMES projetc (fig . 4.1). The objective is to relate zooplankton community composition to environemetal conditions and to compare the information obtained with the Waterframe Directive monitoring carried out by AEAP and the International Commission of the Scheldt (ICS). This means that, at present, the Schelde zooplankton community is followed from source till mouth, offering interesting perspectives for research and international management related collaboration.

Fig. 4.1. Sampling locations of the BIOFOZI project



Mer du Nord
Dunkerque
Capelle-La-Grande
St-Folquin
St-Momelin
Aa
Aire-sur-la-Lys
Lys
Erquinghem-Lys
Wervicq
Lille
Don
Deûle
Douai
Brebières
Ferin
Scarpe
La Sensée
Escaut
Nivelles
Fresnes-sur-Escaut
Valenciennes
Jeumont
La Sambre
Tournai
Warcoing
Zingem
Gand
Melle
Bovenschelde
Escaut
Dendermonde
BELGIQUE
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WORMS: World Register of Marine Species. http://www.marinespecies.org/aphia.php

ANNEX 1. Results of multivariate analysis of species and environmental data relationships for 2011, 2012 and 2013 separately.

Table: Results of RDA analysis performed on 2011 data.

Axes	1	2	3	4	Total inertia
Eigenvalues:	0.168	0.131	0.036	0.018	1.087
Species-environment correlations:	0.665	0.788	0.704	0.575	
Cumulative percentage variance					
of species data:	15.5	27.5	30.8	32.5	
of species-environment relation:	42.6	75.7	84.8	89.4	
Sum of all eigenvalues					1.087
Sum of all canonical eigenvalues					0.395

As can be seen from Fig 3.8 and 3.9, the species distribution is spread on a diaoganl between the first and the second axis, the first axis representing the salinity gradient. The lower part of the biplot is characterised by salinity, oxygen and Chla, while the upper part is associated with high nutrient) concentration (NO_3, PO_3 and Si), and also SPM and POC.

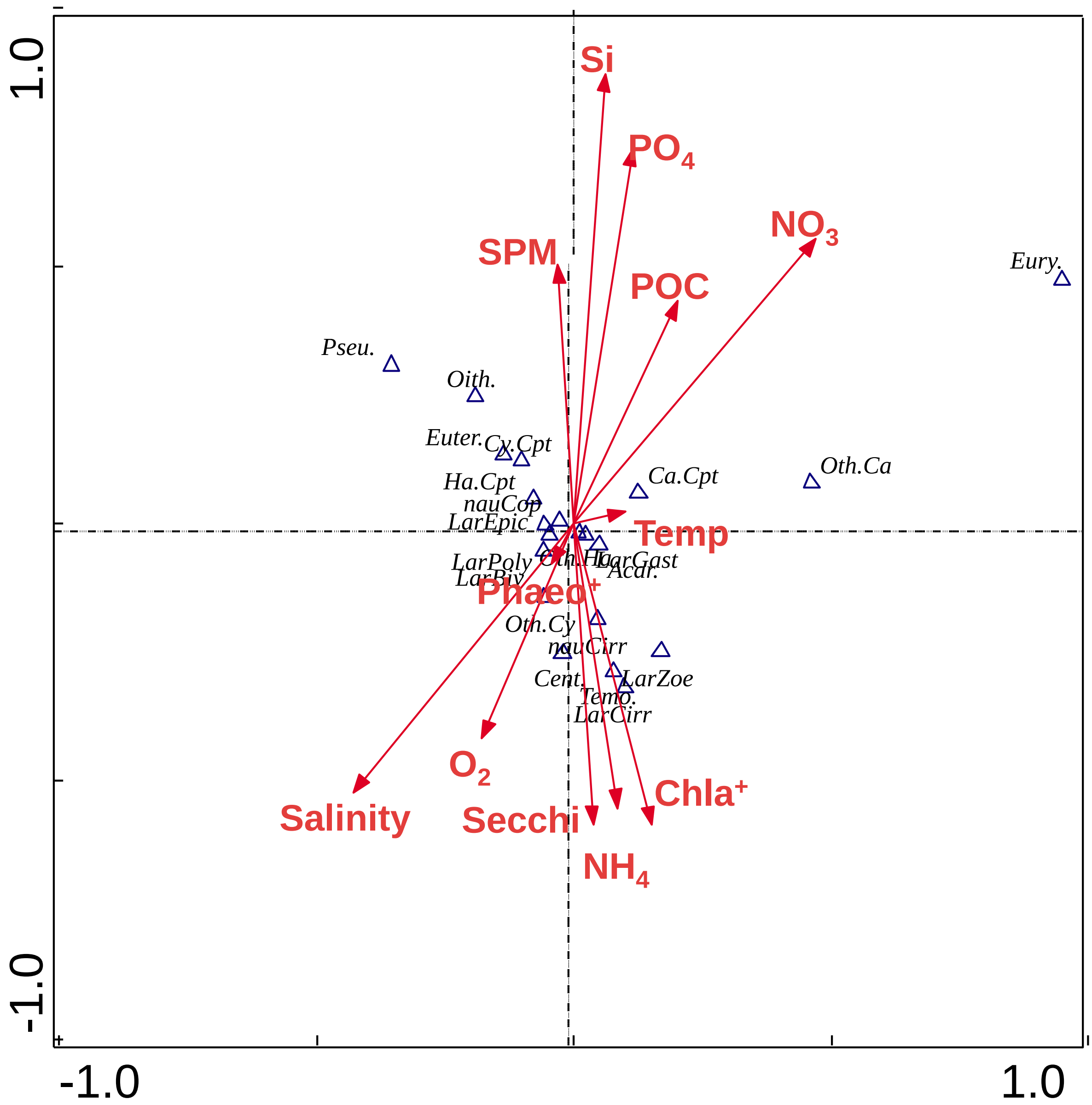

Fig 3.13. Species and environmental factor ordination(axes 1 and 2) of 2011 compiled abundance data.

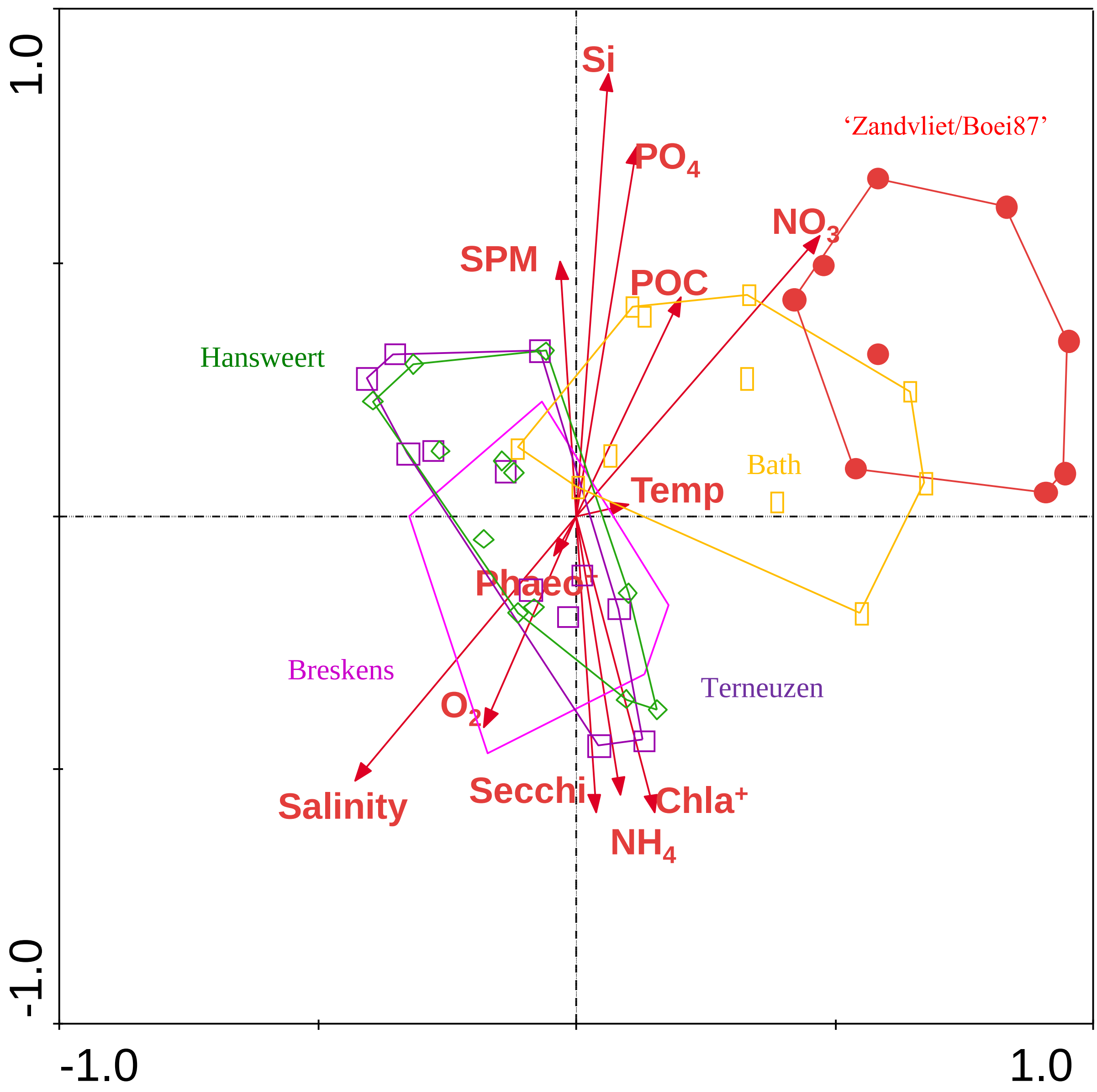

Fig 3.14. Biplot (axes 1 and 2) showing the grouping of samples per station based on their biotic and abiotic characteristics in 2011.

Table: Results of RDA analysis performed on 2012 data.

Axes	1	2	3	4	Total inertia
Eigenvalues:	0.221	0.148	0.056	0.038	1.105
Species-environment correlations:	0.905	0.945	0.829	0.795	
Cumulative percentage variance					
of species data:	20.0	33.4	38.5	42.0	
of species-environment relation:	39.2	65.3	75.3	82.0	
Sum of all eigenvalues					1.105
Sum of all canonical eigenvalues					0.566

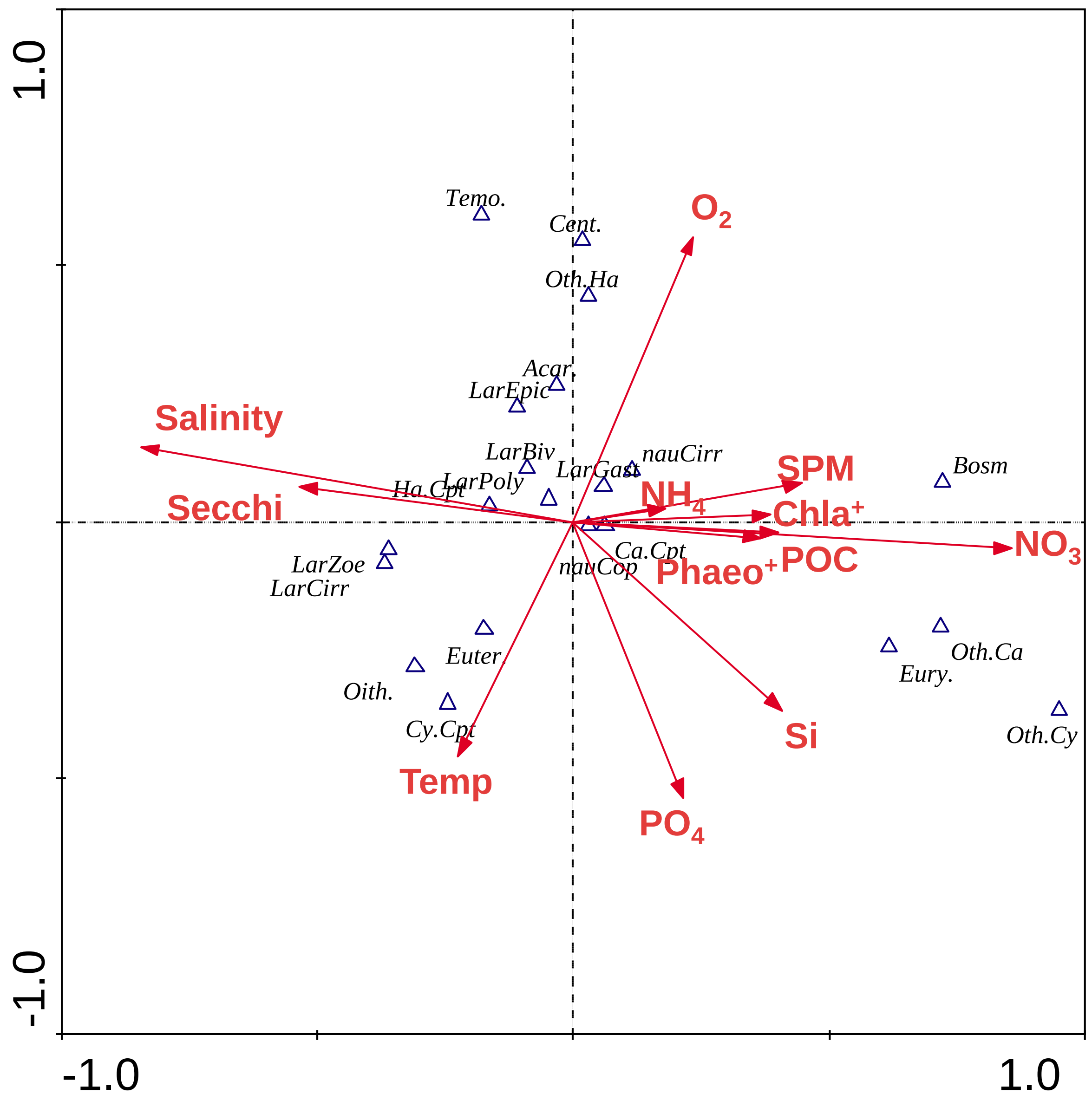

Fig 3.15. Species and environmental factor ordination (axes 1 and 2) of 2012 compiled abundance data.

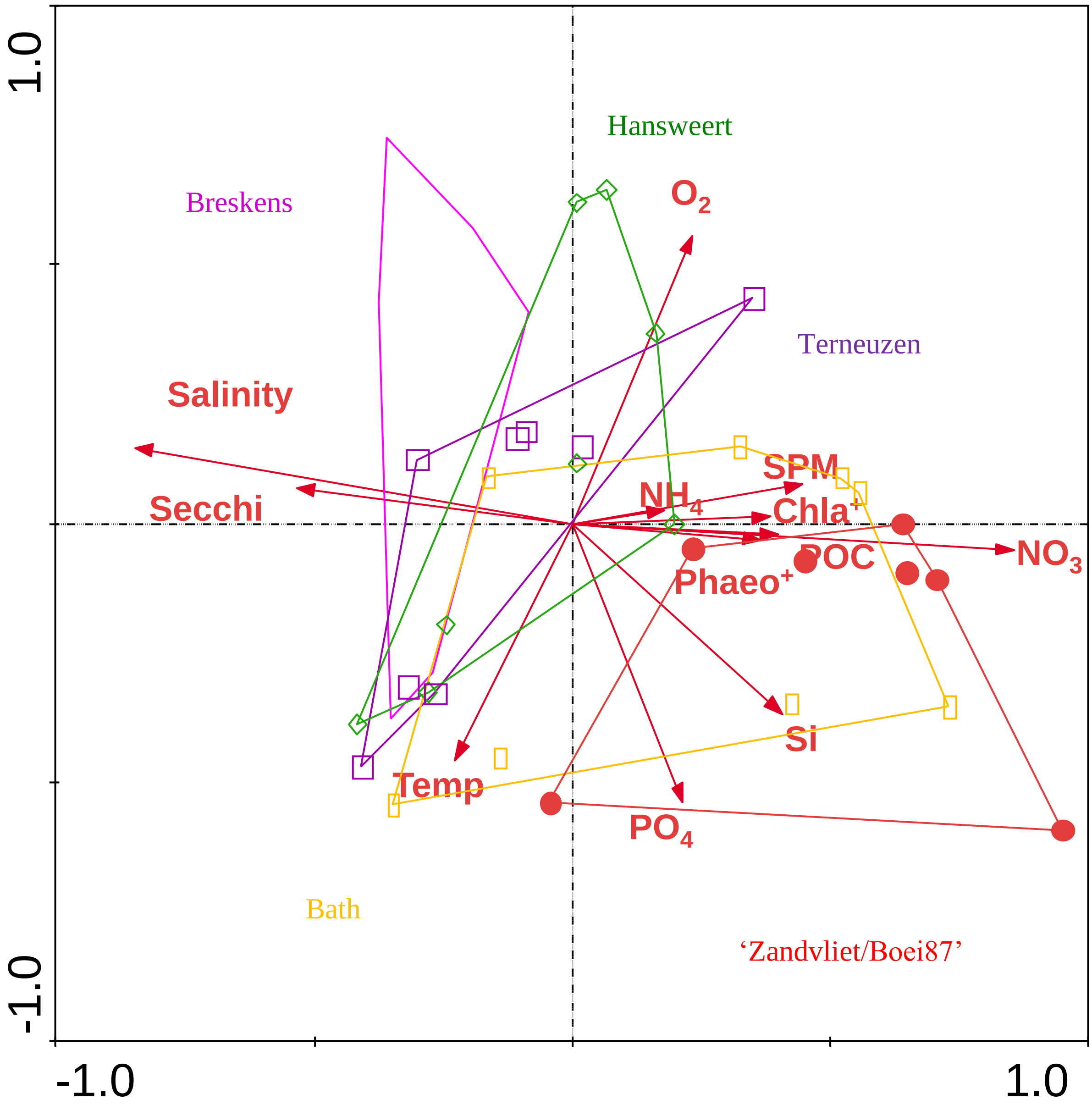

Fig 3.16. Biplot (axes 1 and 2) showing the grouping of samples per station based on their biotic and abiotic characteristics in 2012.

Table: Results of RDA analysis performed on 2013 data.

Axes	1	2	3	4	Total inertia
Eigenvalues:	0.193	0.095	0.072	0.048	0.985
Species-environment correlations:	0.936	0.854	0.829	0.893	
Cumulative percentage variance					
of species data:	19.6	29.2	36.5	41.3	
of species-environment relation:	36.7	54.7	68.5	77.6	
Sum of all eigenvalues					0.985
Sum of all canonical eigenvalues					0.525

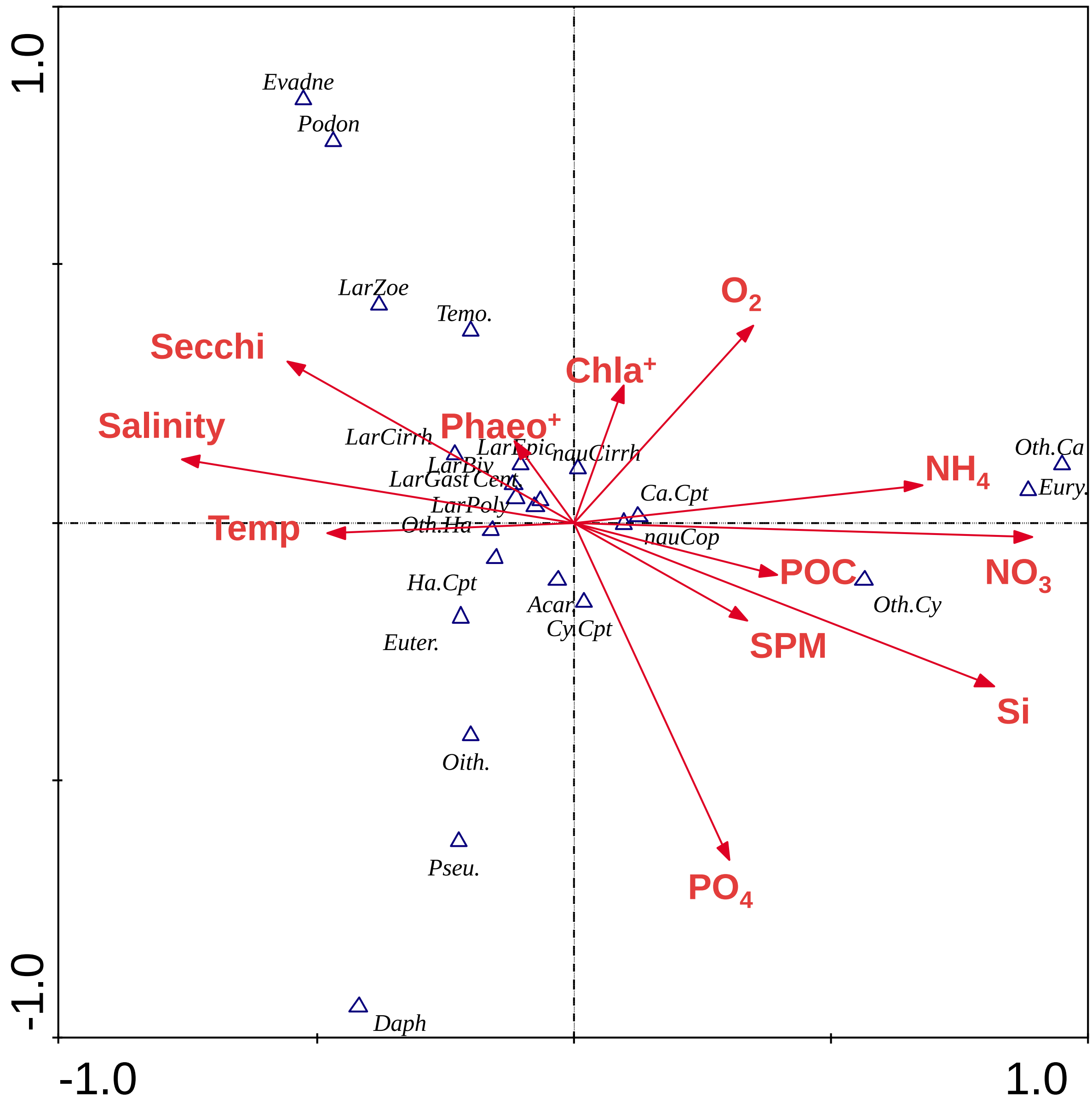

Fig 3.17. Species and environmental factor ordination (axes 1 and 2) of 2013 compiled abundance data.

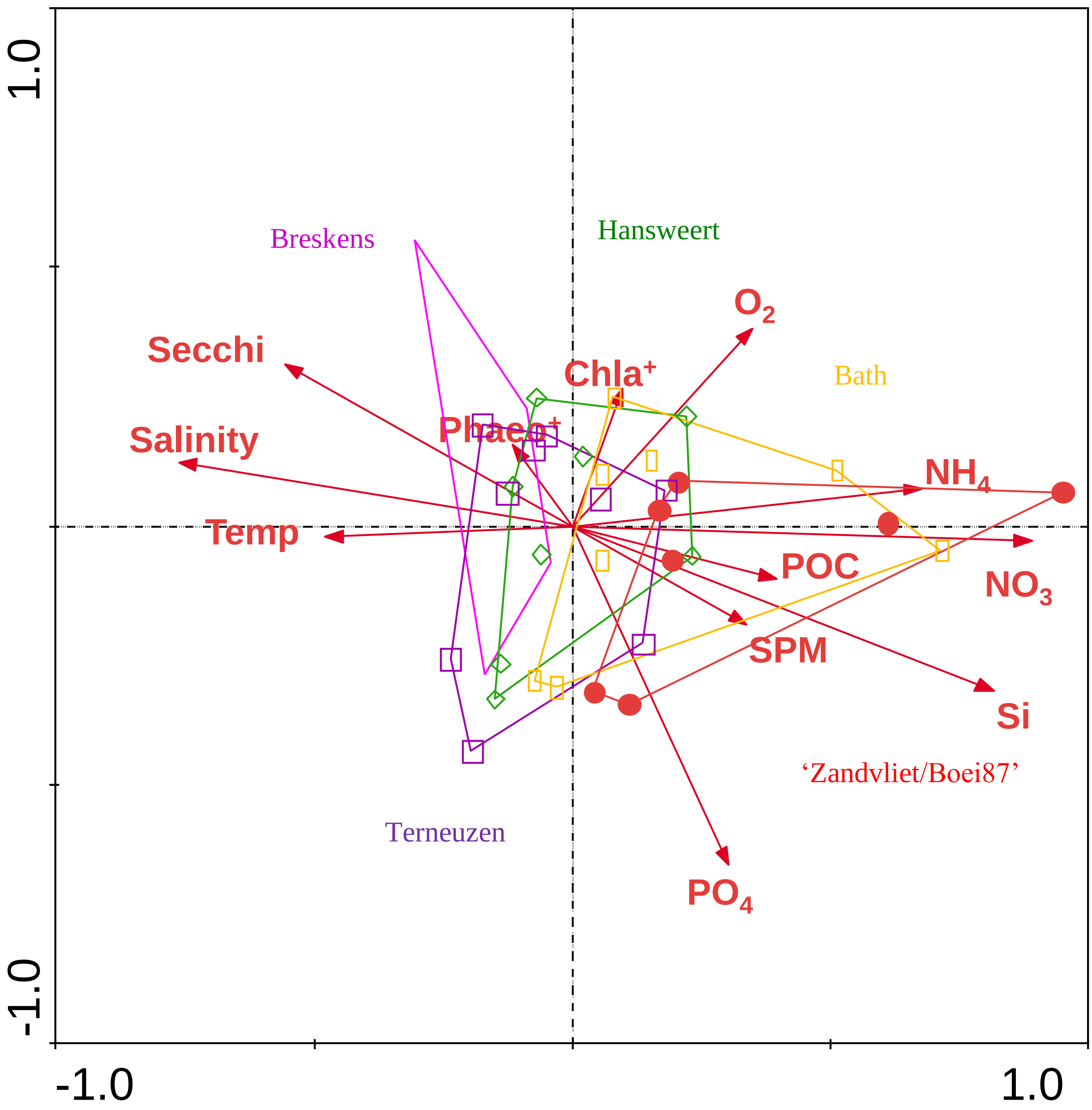

Fig 3.18. Biplot (axes 1 and 2) showing the grouping of samples per station based on their biotic and abiotic characteristics in 2013.