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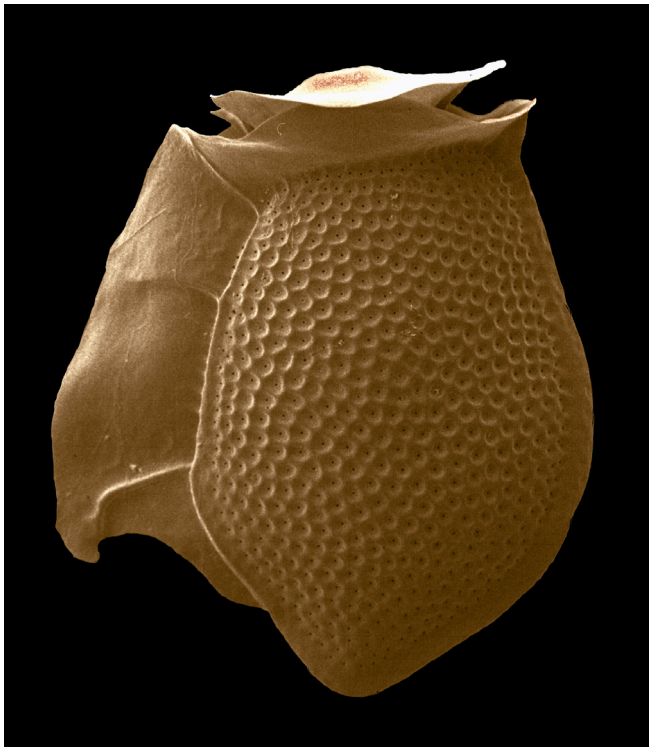

Temporal and spatial distribution of diarrhetic shellfish toxins in blue mussels, *Mytilus edulis* (L.), on the Swedish west coast, NE Atlantic, 1988-2005

Bengt Karlson, Ann-Sofi Rehnstam-Holm & Lars-Ove Loo

SMHI

TJÄRNÖ Marine Biological Laboratory

Cover picture:
Dinophysis acuta, Scanning Electron Micrograph by Bengt Karlson. Artificial colour has been added.

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Title (and Subtitle)/Titel

Temporal and spatial distribution of diarrhetic shellfish toxins in blue mussels, *Mytilus edulis* (L.), on the Swedish west coast, NE Atlantic, 1988-2005.

Abstract/sammandrag

The main goal of this report is to compile and present available data on algal toxins in blue mussels from the west coast of Sweden. The hazards associated with the consumption of mussels are mostly dependent on the occurrence and composition of toxic algae in the areas where shellfish are grown. Diarrhetic shellfish toxins (DST), *i.e.* okadaic acid (OA) and dinophysistoxin-1 (DTX-1) have occurred regularly in blue mussels (*Mytilus edulis*) at the Swedish west coast (i.e. Skagerrak) during the past years. A maximum residue limit of 160 µg·kg^{-1} mussel meat has been set by National Food Administration. The toxic incidences in the region has been linked to the occurrence of *Dinophysis acuminata* and *D. acuta*. In general there is seasonal variation of DST in mussels with low concentrations from March to August (<160 µg·kg^{-1} mussel meat) and high from October to December (>160 µg·kg^{-1} mussel meat). Peaks above the maximum residue limit have in some years also occurred in late June to late July. Rapid intoxication vs. slow detoxification of mussels is a common phenomenon, especially in autumn-winter. Temporal and regional differences are large. There is also a considerable variation in toxin levels between years. In 1994 almost 5000 µg DST·kg^{-1} mussel meat was detected. In 1997 mussel farmers experienced very low levels, i.e. only three samples above the restriction limit of DST. In autumn 1989 to spring 1990 and in early autumn 2000 to early 2001, high levels (about 200 to 2000 µg DTX·kg^{-1} mussel meat) were recorded during 26 weeks. The Koljö Fjord region had low levels of toxins until 1998, despite regular recordings of potentially DST producing algae in the area. Today mussels grown and harvested in this area have similar toxin levels to mussels from other fjords in the Skagerrak region. Measurements of other toxins than DST are few and are not included in the report.

Key words/sök-, nyckelord

Dinophysis, Harmful algal bloom, Kattegat, Skagerrak, marine, DSP, toxins, *Mytilus edulis*, Blue mussel, Common mussel

Supplementary notes/Tillägg

Summaries in both Swedish and English are found in the report

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Contents

Summary in Swedish/Svensk sammanfattning

Målet med denna rapport är att sammanställa och presentera tillgängliga data med algtoxiner i blåmusslor från svenska västkusten. Risken att bli förgiftad av algtoxiner via musslor hänger samman med förekomst och sammansättning av toxiska alger i det vatten där musslorna växer. Diarréframkallande ämnen (diarrheic shellfish toxins), t.ex. okadasyra (OA) och dinophysistoxin-1 (DTX-1) har förkommit regelbundet i blåmusslor (*Mytilus edulis*) längs svenska västkusten (Skagerack) de senaste tjugofyra åren. Ett gränsvärde på 160 µg·kg^{-1} musselkött är fastställt av livmedelsverket. Toxinförekomsten i regionen associeras till förekomsten av *Dinophysis acuminata* och *D. acuta*. "Normalt" är det en säsongsvariation av DST i musslor med låga koncentrationer från mars till augusti (<160 µg·kg^{-1} musselkött) och höga från oktober till december (>160 µg·kg^{-1} musselkött). Toppar över gränsvärdet för konsumtion har vissa år förekommit från slutet av juni till slutet av juli. En snabb ökning i toxinhalt respektive långsam minskning är också ett vanligt förekommande fenomen, speciellt under höst-vinter. Tidsmässiga och regionala skillnader är stora. Det är också en stor skillnad i toxinhalt mellan åren. 1994 uppmättes den högsta toxinhalten till nästan 5000 µg DST·kg^{-1} musselkött. Under 1997 var halterna låga under hela säsongen, endast vid tre tillfällen var halterna över gränsvärdet. Från hösten 1989 till våren 1990 och från tidig höst 2000 till tidig vår 2001 uppmättes höga halter (ca 200 to 2000 µg DTX·kg^{-1} musselkött) under 26 veckor i en följd. I Koljöfjorden var det låga halter av toxiner fram till år 1998, trots förekomst av potentiellt DST producerande alger i området. I dag har musslor som växer och skördas i detta område ungefär samma nivåer av toxin som från andra områden. Mätningar av andra algtoxiner än DST är fåtaliga och tas inte upp i rapporten.

Summary

The main goal of this report is to compile and present available data on algal toxins in blue mussels from the west coast of Sweden. The hazards associated with the consumption of mussels are mostly dependent on the occurrence and composition of toxic algae in the areas where shellfish are grown. Diarrhetic shellfish toxins (DST), *i.e.* okadaic acid (OA) and dinophysistoxin-1 (DTX-1) have occurred regularly in blue mussels (*Mytilus edulis*) at the Swedish west coast (i.e. Skagerrak) during the past years. A maximum residue limit of 160 µg·kg^{-1} mussel meat has been set by National Food Administration. The toxic incidences in the region has been linked to the occurrence of *Dinophysis acuminata* and *D. acuta*. In general there is seasonal variation of DST in mussels with concentrations low from March to August (<160 µg·kg^{-1} mussel meat) and high from October to December (>160 µg·kg^{-1} mussel meat). Peaks above the maximum residue limit have in some years also occurred in late June to late July. Rapid intoxication vs. slow detoxification of mussels is a common phenomenon, especially in autumn-winter. Temporal and regional differences are large. There is also a considerable variation in toxin levels between years. In 1994 almost 5000 µg DST·kg^{-1} mussel meat was detected. In 1997 mussel farmers experienced very low levels, i.e. only three samples above the restriction limit of DST. In autumn 1989 to spring 1990 and in early autumn 2000 to early 2001, high levels (about 200 to 2000 µg DTX·kg^{-1} mussel meat) were recorded during 26 weeks. The Koljö Fjord region had low levels of toxins until 1998, despite regular recordings of potentially DST producing algae in the area. Today mussels grown and harvested in this area have similar toxin levels to mussels from other fjords in the Skagerrak region. Measurements of other toxins than DST are few and are not included in the report.

Preface

Regular monitoring of diarrhetic shellfish toxins in blue mussels using chemical methods started in 1988. Several people and institutes have been involved in sampling and analysis and without their effort it would not have been possible to produce this report. One of the pioneers was Professor Lars Edebo at the Sahlgrenska University Hospital in Göteborg. The Department for Medical Microbiology at Sahlgrenska continued the routine analysis in 2000. Since then the National Food Administration has commissioned the private company AnalyCen AB in Lidköping for the analyses. The mussel farmers, the Water Quality Association of the Bohus Coast, the National Food Administration, several research projects and others have contributed to the funding for sampling and analyses. Staff at SMHI have aided in compiling the data in a structured format from raw data available in various formats. All the effort involved in producing the data presented in this report is greatly acknowledged. This work was initiated after trying to summarize the algal toxin situation for a report for the Oslo-Paris commission (Karlson and Rehnstam-Holm, 2002) and some of the work was carried out as part of the EU project HABES (Harmful Algal Bloom Expert System) contract EVK2-CT-2000-00092.

The report was produced in co-operation, by the Oceanographic unit in Göteborg, Swedish Meteorological and Hydrological Insitute, the Institution of Marine Ecology, Tjärnö Marine Biological Laboratory, Göteborg University and the University of Kristianstad.

Bengt Karlson February 2007

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1 Introduction

1.1 Description of the area

Mussel farms along the Swedish west coast are situated in fjords or in the archipelago along the eastern boundaries of the Kattegat and the Skagerrak in the North East Atlantic. One characteristic of the area is that the tidal amplitude is less than 30 cm. The Kattegat surface water is strongly influenced by the outflow of brackish water from the Baltic that forms a surface layer with a salinity of ca 15 ‰ in the Southern part. Surface salinity increases northward along the coast to ca 25 ‰ in the North-eastern Skagerrak. Water originating from the North Sea is found below a pronounced halocline at a depth of about 15 m. The salinity in the deep water range from 32 to 34 ‰. The Kattegat and the Skagerrak have surface areas of about 22 000 and 32 000 km^2 and mean depths of 23 m and 210 m, respectively. In the fjords along the coast local conditions such as sills and freshwater input from rivers change the general pattern. Anthropogenic input of nutrients has resulted in eutrophication in several areas. Oxygen depletion in the Kattegat is a common event in autumn and some of the fjords have more or less permanent oxygen depleted deep water.

Figure 1. The arrows shows the dominating current pattern in Skagerrak and Kattegat above the halocline.

1.2 Aquaculture – short description and history

Blue mussels (*Mytilus edulis*) are important filter feeders in Swedish coastal waters and long-line blue mussel culturing systems have been in common use in Skagerrak since the early 1980s (Ackefors & Haamer 1987). The first mussel cultures were introduced to the area in 1971 (Loo & Rosenberg 1983). The mussels are grown on hanging, 6-meter suspenders attached to horizontal lines. Normally the larvae settlement occurs abundantly in June (about 2500–10000 ind.·m^{-1} suspenders) along the Skagerrak coast. The gross production capacity of an average Swedish long-line unit is 140 to 200 tonnes of mussels in 18 months (Loo & Rosenberg, Haamer 1995). Each long-line unit occupies a water surface area of about 2000 m^2 and acts as a large three-dimensional bio-filter (10 x 200 m, ~8 m deep). An optimal site on the Swedish West

Figure 2. Swedish long-line culture from the surface on the picture to the right and under water on the left picture. Photo Lars-Ove Loo.

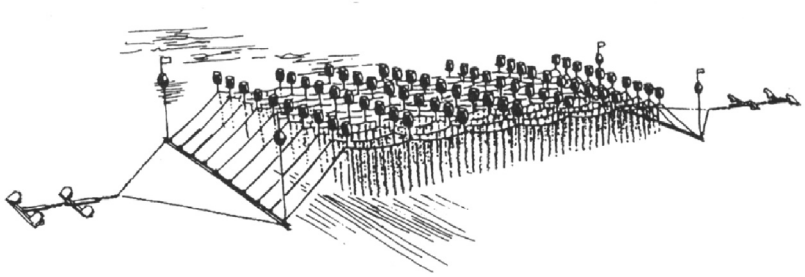


Figure 3. A schematic drawing of a Swedish long-line culture (After Haamer, 1995).

Coast can produce up to 40 kg of fresh mussels per m^2 and year, filtering off the phytoplankton biomass produced by about 25 m^2 of sea surface (Haamer, 1995).

1.3 Algal blooms

High biomass blooms

Algal blooms are common and, in general, natural phenomena in the area. In the end of February or in March the diatom spring bloom usually occurs. The biomass of phytoplankton usually reaches the yearly peak during the spring bloom and since zooplankton such as copepods grow slower than the diatoms a large part of the spring bloom ends up on the sea floor where filter feeders and other benthic animals utilize this resource. Diatoms, dinoflagellates and other flagellates often form blooms during the rest of the growing season but biomass is in general lower since zooplankton feed on the blooms. In May-June blooms of flagellates harmful to fish and other organisms have occurred in several years. In 1988 *Chrysochromulina polylepis*, formed a devastating bloom. *Chattonella* cf. *verruculosa* (proposed new name *Verrucophora verruculosa*) caused fish kills in 1998 and also bloomed in 2000, 2001, 2004 and 2006. The coccolithophorid *Emiliania huxleyi* has formed spectacular blooms in the North Sea-Skagerrak area in May-June in several years. In 2004 the bloom reached the Bohus coast and the water was discoloured turquoise from

Figure 4. Blue mussels growing on polypropylene suspenders in a mussel culture. Photo Lars-Ove Loo.

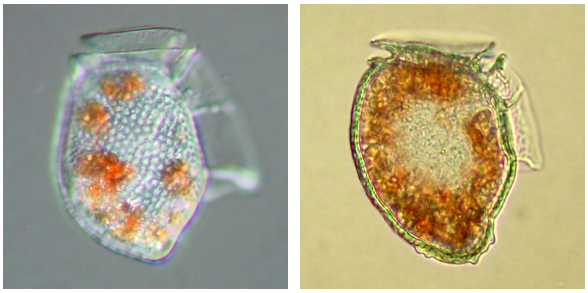


Figure 5. *Dinophysis acuta* (left) and *D. norvegica* (right). Photo Mats Kuylenstierna.

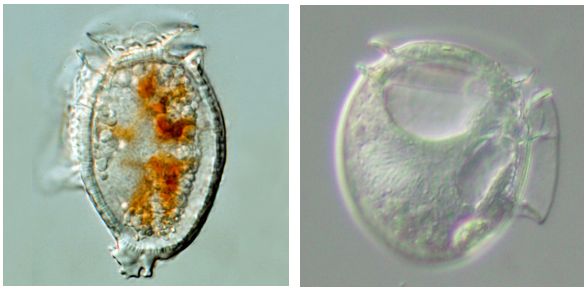


Figure 6. *Dinophysis acuminata* (left) and *Phalachroma rotundatum* (right). Photo Mats Kuylenstierna.

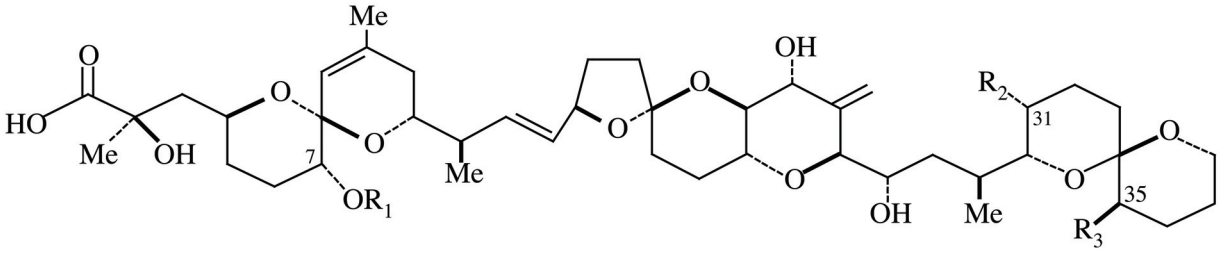
the calcite plates covering the algal cells. This alga is harmless. During summer really small cyanobacteria (1/1000 mm in diameter) dominate production but biomass is in general low. Diatom blooms are common in autumn.

Blooms of the diatom genus *Pseudonitzschia* frequently occur in the Skagerrak and the Kattegat (Karlson *et al.* 2005). Several species from this genus produce domoic acid and cause Amnesic Shellfish Poisoning (ASP). The toxin has been detected in shellfish in Denmark and Norway. In Denmark levels above the regulatory limit were detected in 2004. The dataset on Amnesic Shellfish Toxins (AST) in blue mussels in Sweden is very small and has not been included in this report.

Low biomass blooms causing shellfish toxicity

The most important harmful algae for mussel harvesting occur in low cell numbers and do not form high biomass blooms. Along the Swedish West coast the most potent toxins are produced by dinoflagellates belonging to the genus *Alexandrium*. Some of these produce Paralytic Shellfish Toxins (PST) causing Paralytic Shellfish Poisoning (PSP), which can lead to death. *Alexandrium* spp occur regularly along the Bohus coast, most often in late spring (Karlson *et al.* 2005). The dataset on PST in blue mussels is too small to be included in the present report. Other toxin producing dinoflagellates include *Lingulodinium polyedrum* and *Protoceratium reticulatum*. These two species are known to produce yessotoxins that are not considered a health risk for humans and are thus not discussed further in this report.

Diarrhetic Shellfish Poisoning DSP is the predominant threat to mussel farmers and consumers in Sweden. The phytoplankton species in Sweden that have been linked to DSP can be found within the *Dinophysis* genera, *i.e. D. acuminata* Claparède *et* Lachmann, *D. acuta* Ehrenberg, and to a minor extent *D. norvegica* Claparède *et* Lachmann and *D. rotundata* Claparède *et* Lachmann. The last species is heterotrophic and synonymous with *Phalacroma rotundatum* (Claparède *et* Lachmann) Kofoid *et* Michener 1911 while the others are mixotrophic organisms. *Dinophysis* spp are relatively large (ca 40-100 µm) planktonic organisms that occur year round in the area. Cell numbers are most often below 1000 cells·l^{-1} (Fig. 9; Karlson *et al.* 2005). Warnings for toxin risk in blue mussels are issued at cell densities of 300 cells·l^{-1} for *D. acuta* and at 100 cells·l^{-1} if occurring three weeks continuously. For *D. acuminata* the warning level is 900 cells·l^{-1}. *D. acuta* in Skagerrak is a potent producer of both OA and DTX-1. *D. acuminata* from the region usually only produces OA although this species has been shown to be a producer of DTX-1 in other regions (Andersen *et al.* 1996). *D. norvegica* has never been proven to produce DST in the Ska-



	R_1	R_2	R_3
Okadaic acid (OA)	H	CH_3	H
Dinophysistoxin-1 (DTX-1)	H	CH_3	CH_3
Dinophysistoxin-2 (DTX-2)	H	H	CH_3
Dinophysistoxin-3 (DTX-3)	acyl	CH_3	CH_3

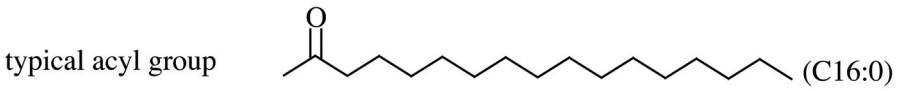


Figure 7. Chemical structure of the causative agents of diarrhetic shellfish poisoning (DSP), okadaic acid and the dinophysistoxins.

gerrak region and *D. rotundata* usually occurs in low numbers and thus does not contribute to the problem. Most attempts to correlate occurrence of *Dinophysis* abundance and the concentration of DST in mussels have failed, except on short timescales and at local sites (*e.g.* Godhe *et al* 2002). One explanation might be the considerable variation of toxin content per *Dinophysis* cell. Another is the characteristic feature of *Dinophysis* blooms, the formation of dense patchy populations in thermoclines or pycnoclines.

Other planktonic organisms that may cause shellfish toxicity do occur along the Bohus coast. In the genus *Protoperidinium* a few species have been shown to cause Azaspirazidic Shellfish Poisoning (AZP). No data on the toxins causing AZP in Swedish waters is known to the authors of this report.

Monitoring of phytoplankton

Routine algal monitoring is performed once a month at 10 stations along the coastline (see Fig. 8) by tube sampling at 0-10 m and 10-20 m. The algae are fixed by Lugol (Uthermöhl 1958) and examined using an inverted microscope at a magnification of 100 to 200.

Phytoplankton sampling and analyses of potentionally toxic species is performed weekly in harvesting areas since 2001. Sampling is performed by personal from National Food Administration. Analyses are made by SMHI since 2004. The data has not been included in this report.

Monitoring of DST

The EC regulation for controlling DST in bivalves is based on a mouse bioassay. This test has the advantage of detecting unknown toxins that might appear in the area. However, the mouse test is semiquantitative and not always satisfactory in terms of detectability, specificity, and reliability. Use of animals in shellfish monitoring programmes has also become increasingly unacceptable in several EU countries for ethical reasons. Analyses by chemical methods have however other disadvantages. These include low ability in detecting new toxins and usually problems to obtain pure toxin standards needed in the tests. The surveillance of the DST concentrations in mussels in Sweden has been performed by HPLC (High Performance Liquid Chromatography) for 14 years (Haamer *et*

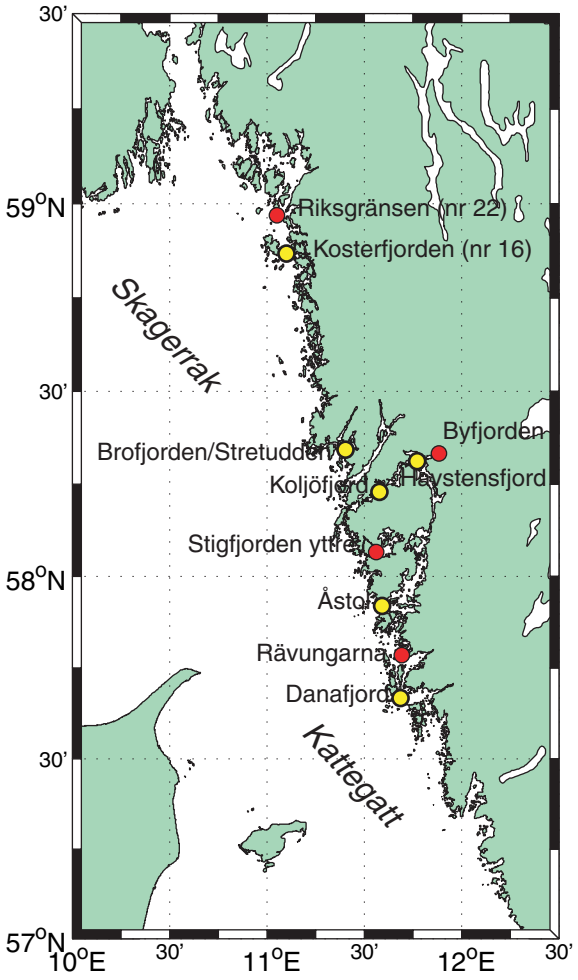


Figure 8. Locations for quantitative phytoplankton monitoring from 1990 to 2003. Some locations have only been visited a short time, others are new and some others are finished. Yellow markers indicate stations still active in 2006 while stations with red markers have been discontinued. From Karlson *et al.* (2006).

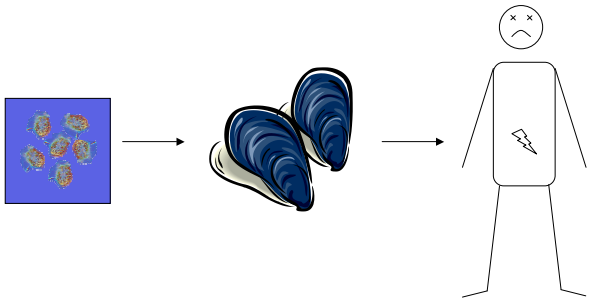


Figure 9. Toxic algae (*Dinophysis* spp.) -> suspension feeder (*Mytilus edulis*) -> human.

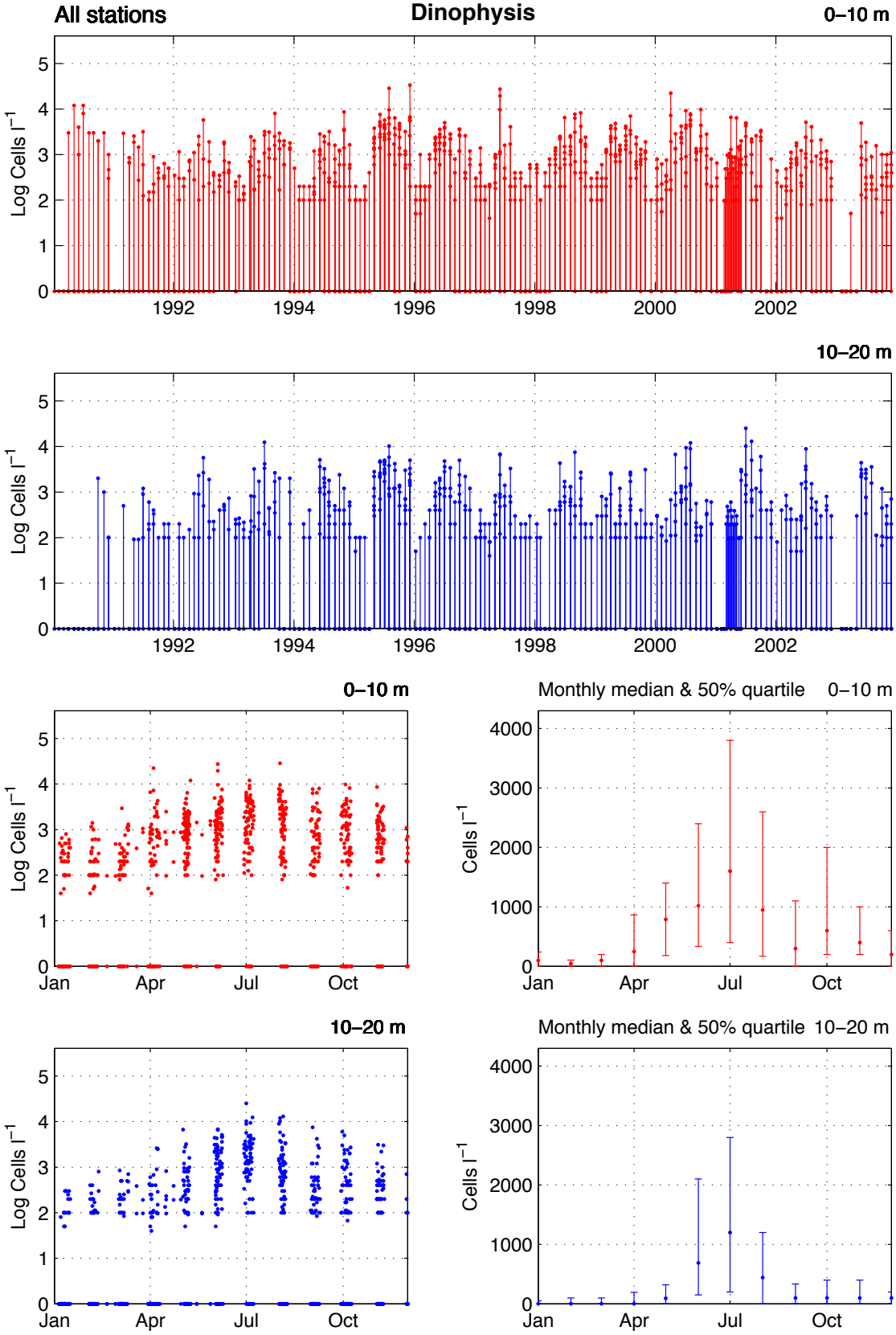


Figure 10. From Karlson, B., Edler, L., Skjevik, A.-T. och Claesson, S. (2005). Växtplankton vid Bohuskusten - förstudie till utvärdering av miljöövervakningsdata 1990-2003. SMHI rapport 2005-70, pp. 58. The two graphs on the top show the number of dinoflagellates of the genus *Dinophysis* per litre from 0-10 m depth (red) and 10-20 m (blue) respectively. The graphs on the left show seasonal variations from raw-data. To the right the same data is shown as median, + 75 % quartile and - 25 % quartile.

al. 1999). From the middle of 2000 the analyses were transferred to a commercial company, AnalyCen Nordic AB, and the method of choice was subsequently changed to HPLC-MS (HPLC with Mass Spectrometrical detection). The National Food Administration administers the monitoring of harmful algae and algal toxins in shellfish as well as opening and closing of harvesting areas to make sure that mussels are safe to eat (Nordlander, 2006). The "Water Quality association of the Bohus Coast" as well as mussel farmers and research projects has funded the Swedish analyses. Starting in 2001 the sampling program has been co-ordinated and partly funded by the Swedish National Food Administration.

2. Material & methods

2.1 Description of collected data

For routine monitoring of DSP, 15 mussels, five from the upper (1 m), five from the middle (5 m), and five from the bottom (8 m) of the mussel culturing band, are collected and weighed after removal of the shells. The hepatopancreas is dissected and weighed separately for determination of the relative proportions, which can vary from 10-25 % and result in a total of 10-30 g hepatopancreas (HP). On average three samples a week are analysed for each area. This can however change due to time of year and with toxin levels in the mussels since many data are obtained from analyses of samples from mussel farmers. OA has been regularly monitored since 1988, DTX-1 between 1992-2000 with the exception of 1996.

2.2 Analysis methods

2.2.1.Mouse bioassay

The mouse bioassay was the first test developed to monitor DSP toxins in shellfish extracts (Yasumoto *et al.* 1978) and this test is still widely used. The main principle of the bioassay is to inject shellfish extracts intraperitoneally into a mouse and monitor the reaction. Time of death is ideally related to the amount of toxin in the injected extract and the amount is calculated from a standard curve as mouse units (MU). MU are defined as amounts of toxin required to kill two to three 20 g mice in 24 hours, such that one MU corresponds to 4 µg OA, 3.2 µg DTX-1 and 5 µg DTX-3 (Yasumoto *et al.* 1995). The limit for marketing of shellfish within EU is 160 µg OA·kg^{-1} mussel meat. This corresponds to the detection limit for the mouse bioassay. Most Swedish mussels that are exported to the EU market are still analysed by the mouse bioassay.

2.2.2. Rat bioassay

The rat bioassay was the first test ever performed to monitor DSP toxins in shellfish (Kat, 1983). In this test the digestive glands (or hepatopancreas) of mussels were dissected from the mussels and fed to rats. The fecal pellets from the rats were thereafter examined and if the rats showed symptoms of diarrhoea the test was considered positive. Rat tests were performed sporadically during 1988-2000 in Sweden on chemically negative mussel samples.

2.2.3. Analytical procedure by HPLC using PDAM

A modified instrumental method using HPLC with fluorescence detection according to Lee *et al.* was used between 1988-2000 (Lee *et al.* 1987). A detailed description of the method can be found in Rehnstam-Holm *et al.* (submitted). In this method derivatization with 9-anthryldiazomethane (ADAM) is used to convert the toxins to fluorescent ester derivatives. Problems with the stability of this substance initiated the search for a new reagent, and 1-pyrenyldiazomethane (PDAM) was found to be a good alternative.

The hepatopancreas sample was homogenised and 1.0 g of the homogenate was further used in the analysis. The toxins were extracted in methanol, delipidized by extraction with petroleum ether, and further extracted with a chloroform:water mixture. The chloroform layer was evaporated to dryness and derivatizised with a PDAM solution in methanol-ethyl acetate. The derivatized sample was concentrated on a silica gel cartridge column and the sample was eluted using methanol in chloroform. The elute was evaporated to dryness, and the residue was dissolved in methanol prior to HPLC analysis.

The samples were analysed using a reversed-phase column Kromasil 5 C18. The instrument was calibrated with 10 ng okadaic acid and 5 ng DTX-1, which corresponds to 2 respectively 1 µg g^{-1} hepatopancreas sample. A standard sample

was prepared for calibration and derivatized in the same way as the samples. The recovery yield for okadaic acid was 92 % with a coefficient of variation of 4,8%. The recovery yield for DTX-1 was 90 % with a coefficient of variation of 6.9 %. The detection limit was set to 10 µg OA or DST-1·kg^{-1} mussel meat.

2.2.4. Analytical procedure by HPLC-MS
From the middle of 2000 toxin analyses have been performed by a commercial company, AnalyCen AB in Lidköping by using HPLC-MS. The analytical procedure follows that of Aase & Rogstad (Aase *et al.* 1997).

0.5 µg toxin was added to toxin free mussel hepatopancreas homogenates during every analytical event and a recovery ranging between 70-120 % was accepted. The detection limit with this method was set to 30 µg toxin·kg^{-1} mussel meat.

3. Results

3.1 Collected data

On average three samples a week have been analysed for each area. This has however varied with time of year, toxin levels in the mussels and culturing area, since most data are obtained from analyses of samples from mussel farmers. This means that on occasions with high or very low toxic levels, mussel farmers are less prone to send samples for analyses. Mussel cultivation areas have also been abandoned after long periods of high toxicity in favour of other, less problematic areas.
Algal monitoring samples are usually collected only once a month and at different locations compared to mussel samples (see Fig. 8).

3.2 Occurrence of *Dinophysis* spp. and its correlation to toxicity in mussels

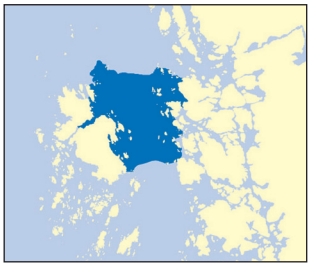
Dinophysis spp. can be observed in plankton samples all over the year in the region at fairly limited numbers, i.e. between 100-10 000 cells·l^{-1}. A regular pattern of *Dinophysis* numbers can be observed during the years (Fig. 9). Highest numbers occur in mid July and during this period the dominating species are *D. acuminata* and *D. norvegica*. An additional smaller peak can be observed in October. Here the dominant species are *D. acuminata* and *D. acuta*. Dominant species as well as toxicity per cell are probably important factors influencing the toxicity accumulated in mussel tissue. Further correlation analyses are however not within the scope of this report and will be published elsewhere.

3.3 Temporal and spatial distribution of total DST

The long Swedish regular analysis of diarrhetic shellfish toxins (from 1988) in mussels along the Skagerrak coast is a unique quantitative dataset. Okadaic acid (OA) has been and still is the dominating DST, but DTX-1 and DTX-2 have occurred occasionally. Regular analyses of DTX-2 started in late 2006 and is not included in this report.
In the figures toxin values are given as µg DST (OA+DTX-1)·kg^{-1} mussel meat. The large data set shows a clear strong seasonal variation in DST concentrations. In *i.e.* typical year high levels of DST in mussel tissue occurs from August until February, while levels are normally low from March until July, a pattern that also can been observed for the mean monthly toxicity for all years and most regions. The amplitude of the peaks differs significantly between years. Years 1989 -1990, 1994 -1995, 1998 and 2000-2002 have been especially bad. In other years 1992, 1997, and 2005, low levels of toxin were recorded with few values above the maximum residue limit (Nordlander, 2006), *i.e.* 160 µg kg^{-1} mussel meat. A summer peak can be observed in most areas in late June - end of July in 1989, 1991, 1993, 1995, and 1998 to 2004. The toxin values in the mussels were during these periods normally below the maximum residue limit, but the pattern was not persistent. In 2002 the summer peak, which reached as high as 1400 µg DTX·kg^{-1} mussel meat, appeared through out the whole Skagerrak area and in some regions (*i.e.* Tjärnö Archipelago, Fig. 13-15), the mussels continued to be toxic until early spring next year. See also the discussion where figures 83 and 84 show the whole data set.

3.4. Kosterfjorden

Water body Inre N Kosterfjorden 585400-110400



There are only two measurements of DST from the water body Inre Kosterfjorden during the whole investigation period 1988 to 2004. These two are from 2002. The upper graph shows DST values during all measured years. The graph in the middle shows the distribution of DST values during the seasonal month of the year. The bottom graph shows the same data in another way, where the highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

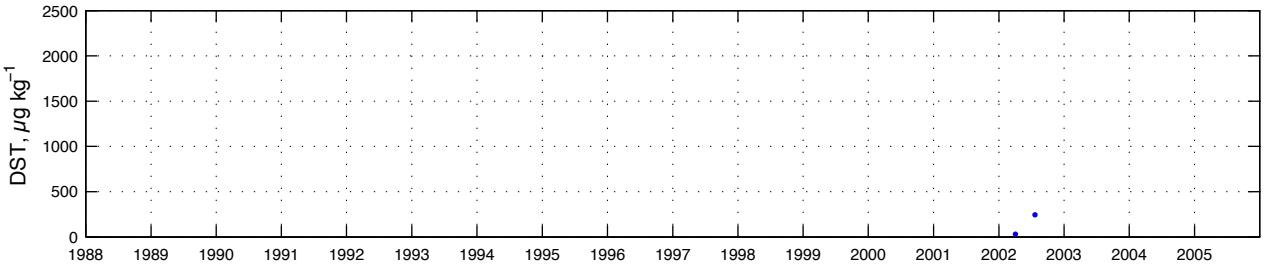


Figure 11. All measurements of DST ($\mu g \cdot kg^{-1}$) in Kosterfjorden from 1988 to 2005.

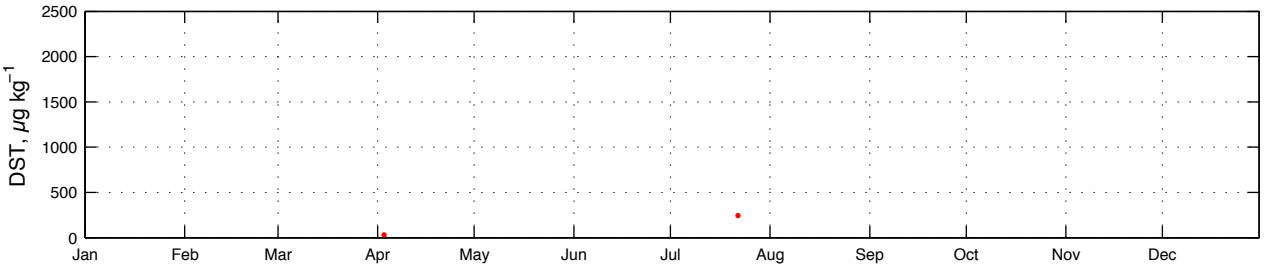


Figure 12. All measurements of DST ($\mu g \cdot kg^{-1}$) in Kosterfjorden from 1988 to 2005 presented during a year-scale.

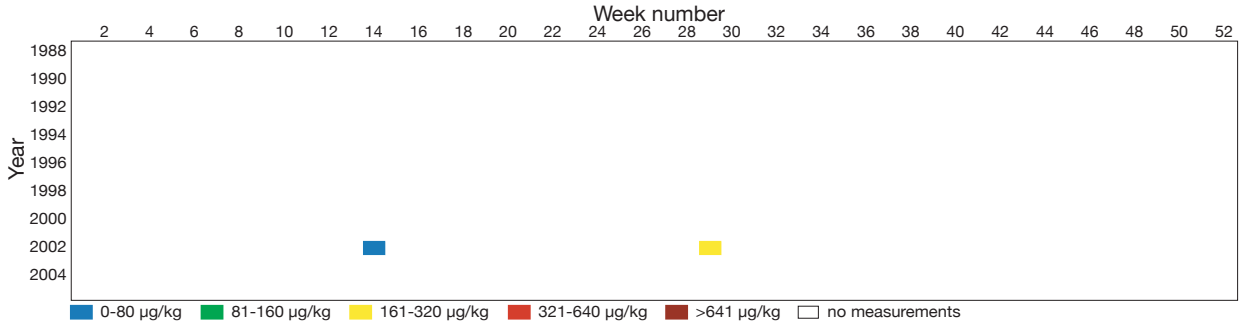
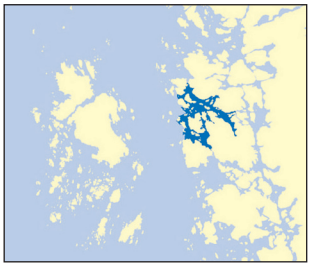


Figure 13. The highest measured value each week is presented with a specific colour. 160 $\mu g \cdot kg^{-1}$ is the regulatory maximum residue limit.

3.5. Tjärnö archipelago

Water bodies Inre Tjärnöarkipelagen 585290-110830
and N Ytrre Tjärnöarkipelagen 585200-111140



The first mussel-culture in Sweden was established in 1971 in the Tjärnö archipelago neighbourhood. Regular sampling in the area started 1988 and has been more or less regular since then. The upper graph shows the variation of DST during all the measured years. Some of the years show very low values, even below the regulatory maximum residue limit (160 µg·kg^{-1}), and some years very high levels. The highest level measured during the whole period was about 2000 µg·kg^{-1} in winter 1993-1994. The graph in the middle shows the distribution of DST values during the year and the pattern clearly shows that high DST values are an autumn-winter problem. The same pattern is shown in the bottom graph but in another way. The highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

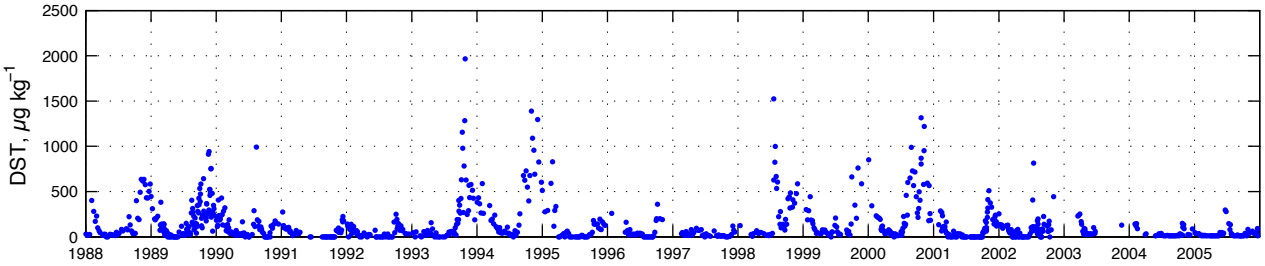


Figure 14. All measurements of DST (µg·kg^{-1}) in Tjärnö archipelago from 1988 to 2005.

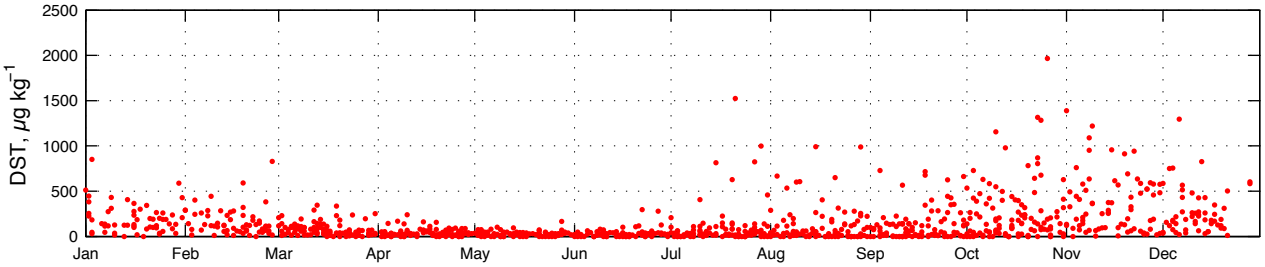


Figure 15. All measurements of DST (µg·kg^{-1}) in Tjärnö archipelago from 1988 to 2005 presented during a year-scale.

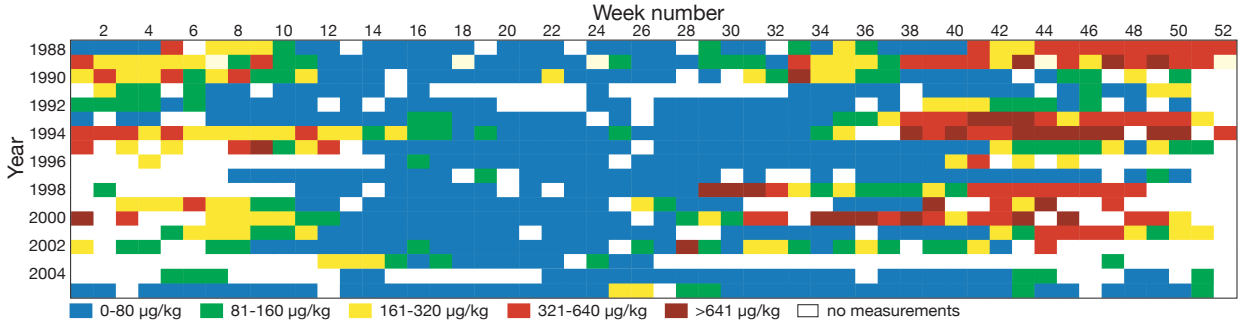
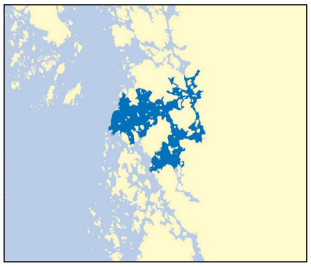


Figure 16. The highest measured value each week is presented with a specific colour. 160 µg·kg^{-1} is the regulatory maximum residue limit.

3.6. Råssö-Resö archipelago

Water bodies Råssö-Resöfjorden sek name 584890-110950 and Stridsfjorden 584750-111185



Sampling in the area started regularly in 1988 and has been more or less regular since then. The upper graph shows the variation of DST during all the measured years. Some of the years show very low values, even below the regulatory maximum residue limit (160 µg·kg^{-1}), and some year very high levels. The highest level measured during the whole period was higher than 2200 µg·kg^{-1} in winter 1988-1989. The graph in the middle shows the distribution of DST values during the year and the pattern clearly shows that high DST values are an autumn-winter problem. The same pattern is shown in the bottom graph but in another way. The highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

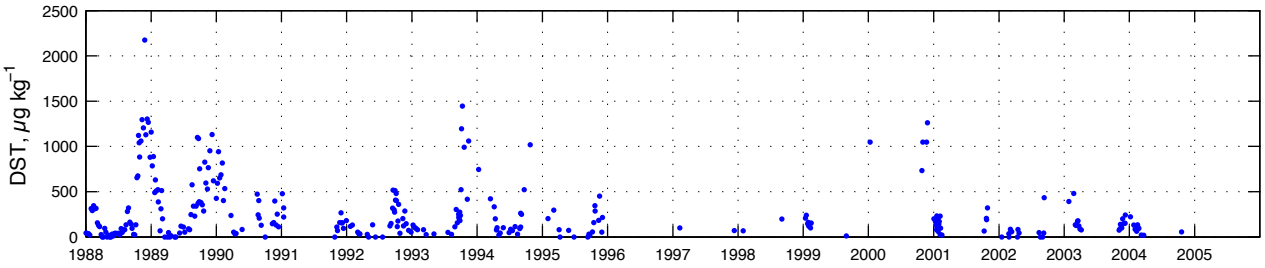


Figure 17. All measurements of DST (μg·kg^{-1}) in Råssö-Resö archipelago from 1988 to 2005.

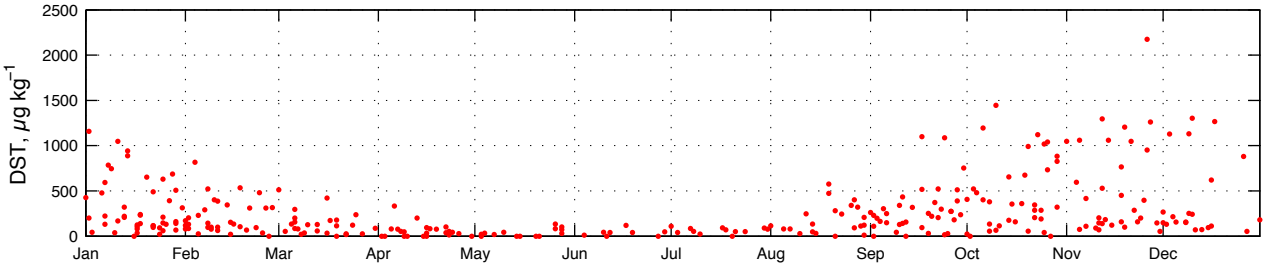


Figure 18. All measurements of DST (μg·kg^{-1}) in Råssö-Resö archipelago from 1988 to 2005 presented during a year-scale.

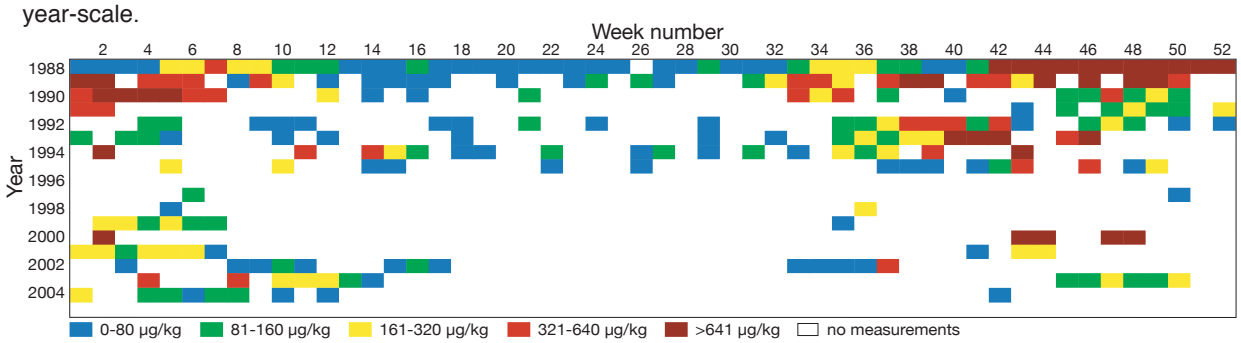
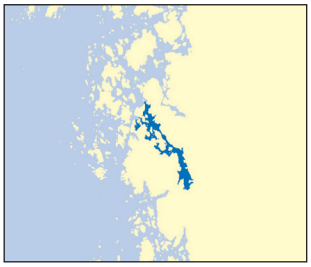


Figure 19. The highest measured value each week is presented with a specific colour. 160 μg·kg^{-1} is the regulatory maximum residue limit.

3.7. Sannäsfjorden

Water body Sannäsfjorden sek name 584450-111445



Sampling in Sannäsfjorden started regularly in 1994 and has been more or less regular since then. The upper graph shows the variation of DST during all the measured years. Some of the years show very low values, even below the regulatory maximum residue limit (160 µg·kg^{-1}), and some year very high levels. The highest level measured during the whole period is just below 1500 µg·kg^{-1} in winter 2000-2001. The graph in the middle shows the distribution of DST values during the seasonal month of the year and the pattern clearly shows that high DST values are an autumn-winter problem. The same pattern is shown in the bottom graph but in another way. The highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

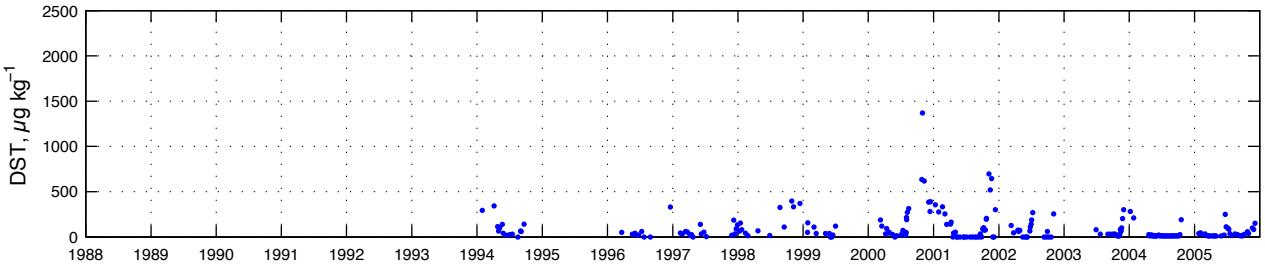


Figure 20. All measurements of DST (µg·kg^{-1}) in Sannäsfjorden from 1988 to 2005.

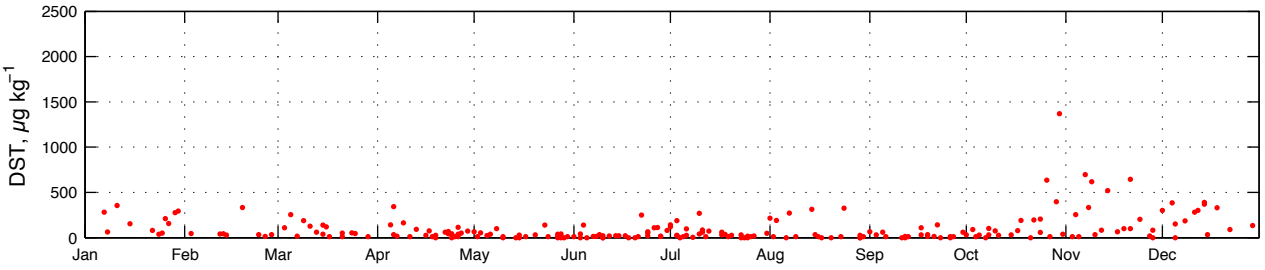


Figure 21. All measurements of DST (µg·kg^{-1}) in Sannäsfjorden from 1988 to 2005 presented during a year-scale.

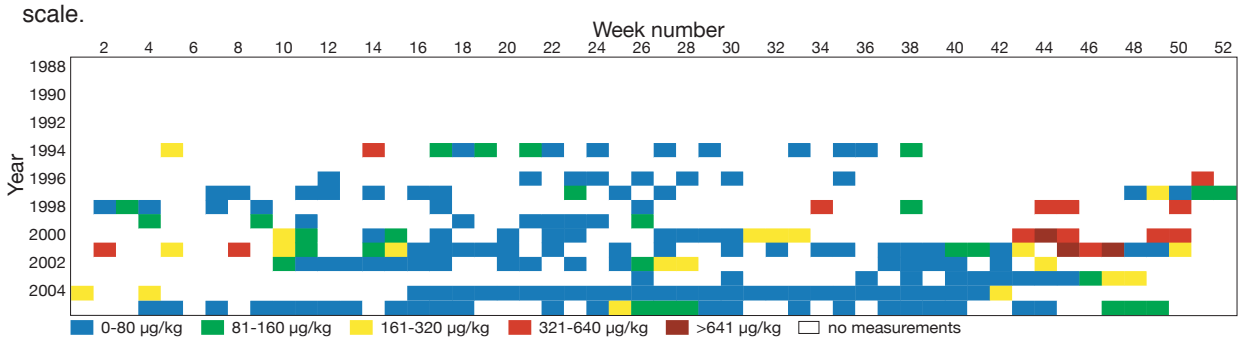
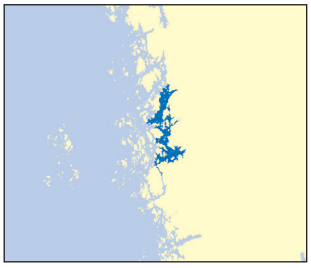


Figure 22. The highest measured value each week is presented with a specific colour. 160 µg·kg^{-1} is the regulatory maximum residue limit.

3.8. Fjällbacka archipelago

Water body Fjällbacka inre skärgård 583710-111535



Sampling in the area started regularly in 1988 and has been more or less regular since then. It was a gap in sampling from 1990 to 1994. The upper graph shows the variation of DST during all the measured years. Some of the years show very low values, even below the regulatory maximum residue limit (160 µg·kg^{-1}), and some year very high levels. The highest level measured during the whole period is just below 1500 µg·kg^{-1} in winter 1994-1995. The graph in the middle shows the distribution of DST values during the seasonal month of the year and the pattern clearly shows that high DST values are an autumn-winter problem. The same pattern is shown in the bottom graph but in another way. The highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

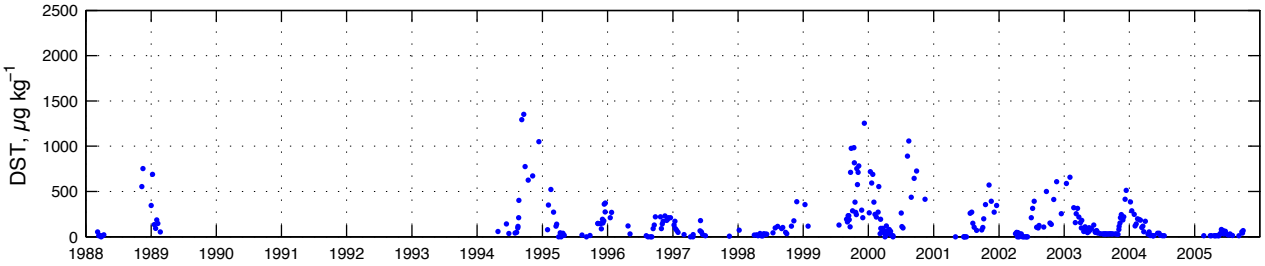


Figure 23. All measurements of DST (µg·kg^{-1}) in Fjällbacka archipelago from 1988 to 2005.

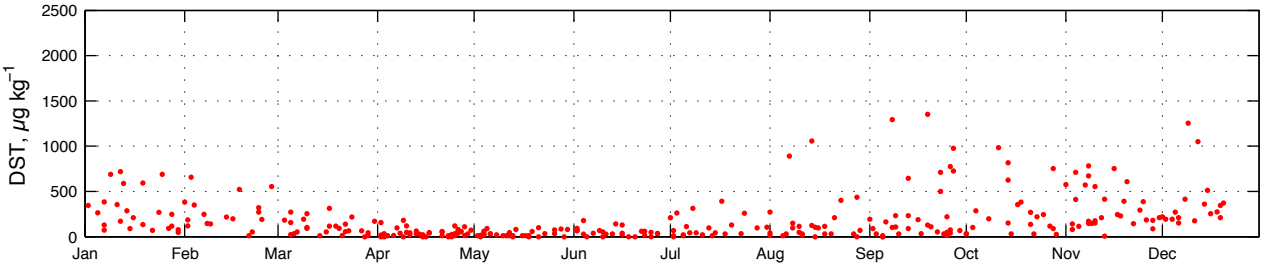


Figure 24. All measurements of DST (µg·kg^{-1}) in Fjällbacka archipelago from 1988 to 2005 presented during a year-scale.

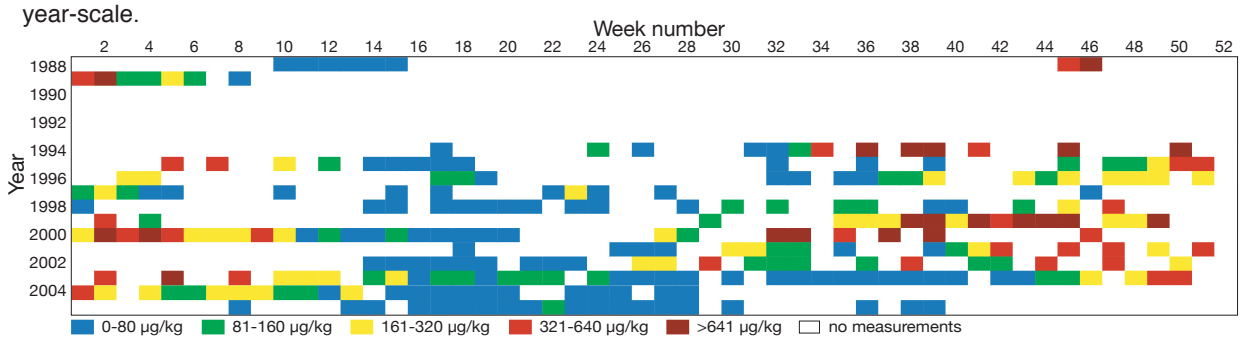
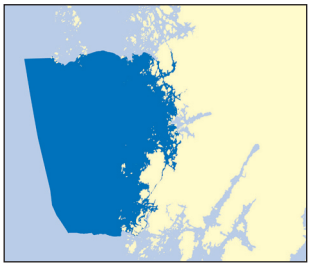


Figure 25. The highest measured value each week is presented with a specific colour. 160 µg·kg^{-1} is the regulatory maximum residue limit.

3.9. Sotefjorden

Water body Sotefjorden 582700-110451 585290-110830



Sampling in Sotefjorden started regularly in 2001. The upper graph shows the variation of DST during all the measured years. Some of the years show very low values, even below the regulatory maximum residue limit (160 µg·kg^{-1}), and some year very high levels. The highest level measured is about 800 µg·kg^{-1} in winter 2002-2003. The graph in the middle shows the distribution of DST values during the seasonal month of the year. The same pattern is shown in the bottom graph but in another way. The highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

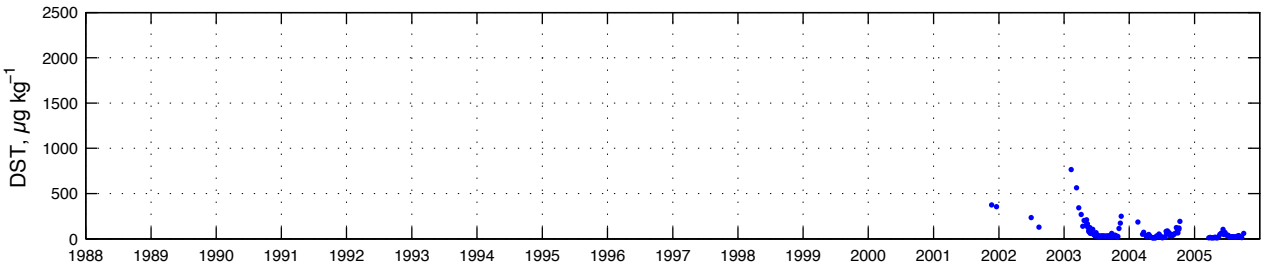


Figure 26. All measurements of DST (μg·kg^{-1}) in Sotefjorden from 1988 to 2005.

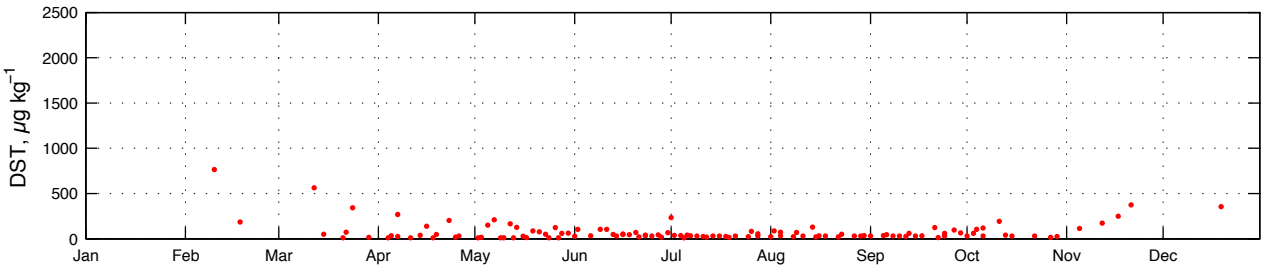


Figure 27. All measurements of DST (μg·kg^{-1}) in Sotefjorden from 1988 to 2005 presented during a year-scale.

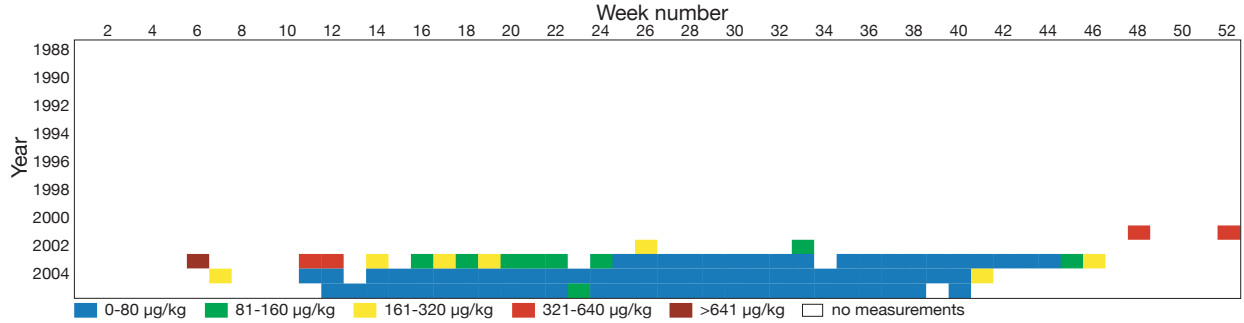
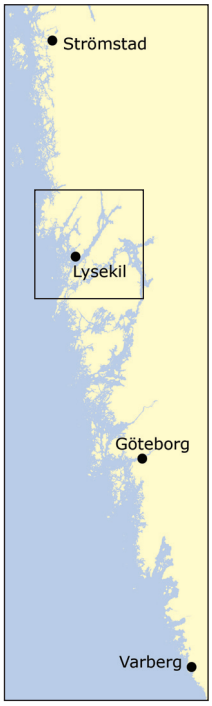


Figure 28. The highest measured value each week is presented with a specific colour. 160 μg·kg^{-1} is the regulatory maximum residue limit.

3.10. Gullmarns centralbassäng

Water body Gullmarns centralbassäng 581700-113000



Sampling in the area started regularly in 1988 and has been more or less regular since then. The data from the Gullmar Fjord is not complete due to inconsistencies in the data set. There are also some concerns about the quality of the presented data for this area. The upper graph shows the variation of DST during all the measured years. Some of the years show very low values, even below the regulatory maximum residue limit (160 µg·kg^{-1}), and some years very high levels. The highest level measured during the whole period was around 2400 µg·kg^{-1} in winter 1988-1989. The graph in the middle shows the distribution of DST values during the seasonal month of the year and the pattern clearly shows that high DST values are an autumn-winter problem. The same pattern is shown in the bottom graph but in another way. The highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

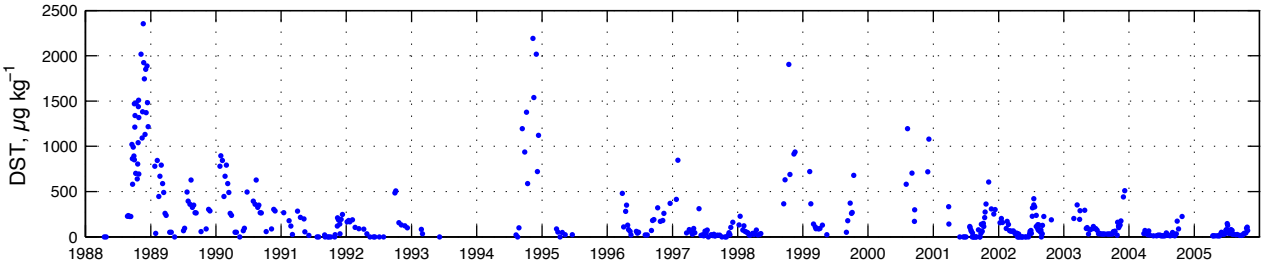


Figure 29. All measurements of DST (μg·kg^{-1}) in Gullmarns centralbassäng from 1988 to 2005.

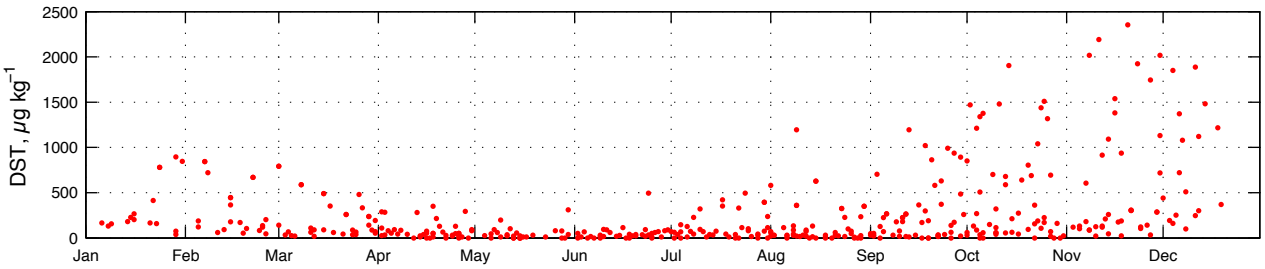


Figure 30. All measurements of DST (μg·kg^{-1}) in Gullmarns centralbassäng from 1988 to 2005 presented during a year-scale.

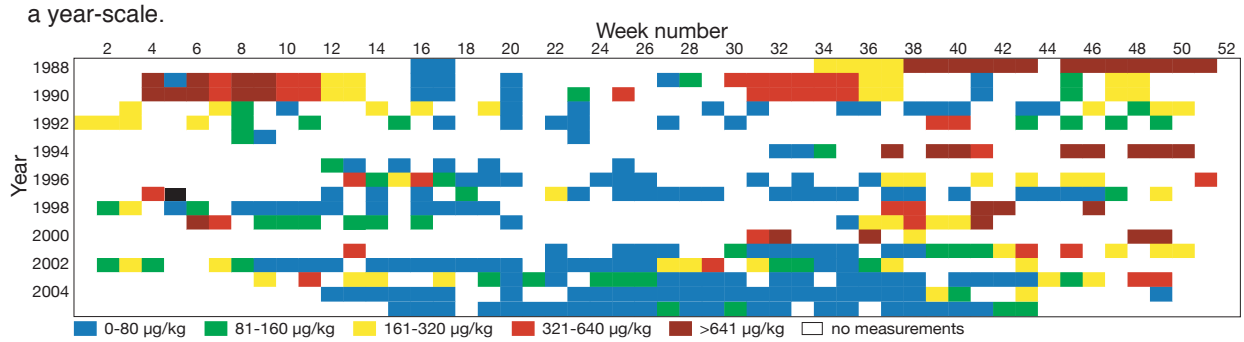
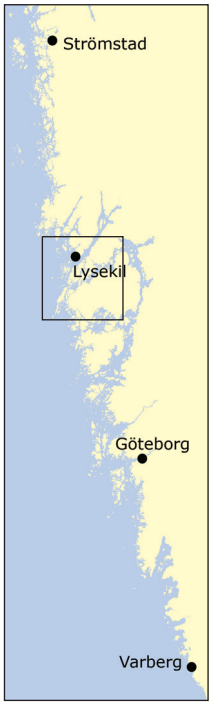


Figure 31. The highest measured value each week is presented with a specific colour. 160 μg·kg^{-1} is the regulatory maximum residue limit.

3.11. Malö strömmar

Water body Malö strömmar 581200-112960



There is only a short sampling period in Malö strömmar from 1995 to 1996. The upper graph shows the variation of DST during all the measured years. All values were below the regulatory maximum residue limit (160 µg·kg^{-1}). The graph in the middle shows the distribution of DST values during the seasonal month of the year. In the bottom graph the highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

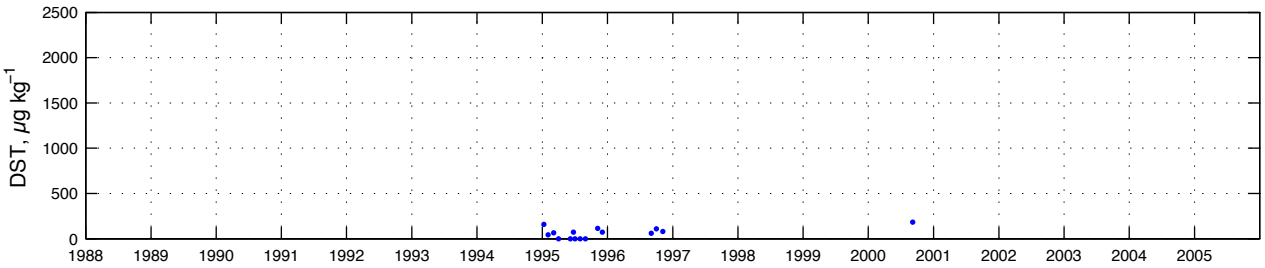


Figure 32. All measurements of DST (μg·kg^{-1}) in Malö strömmar from 1988 to 2005.

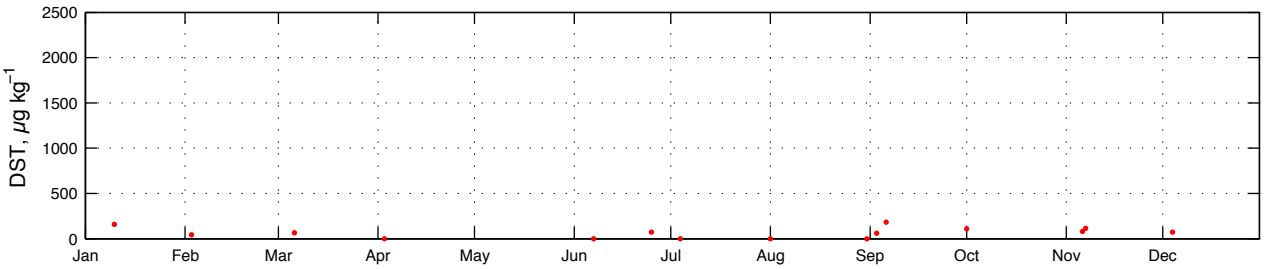


Figure 33. All measurements of DST (μg·kg^{-1}) in Malö strömmar from 1988 to 2005 presented during a year-scale.

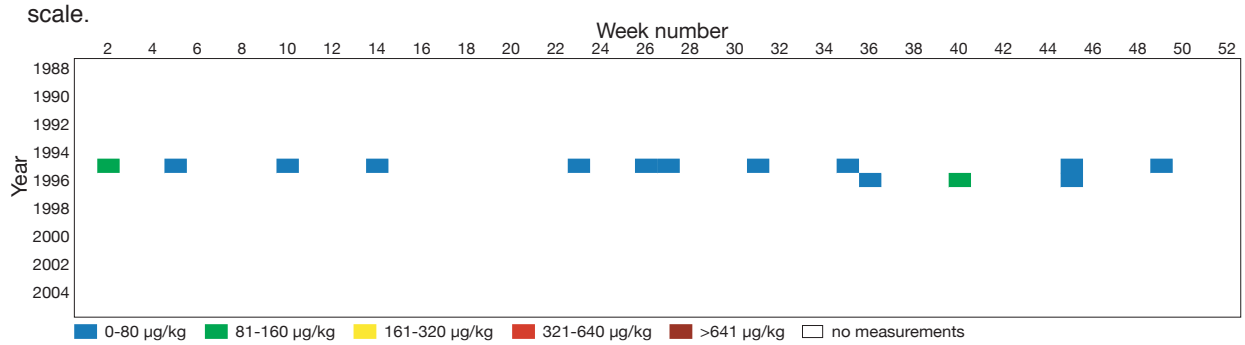
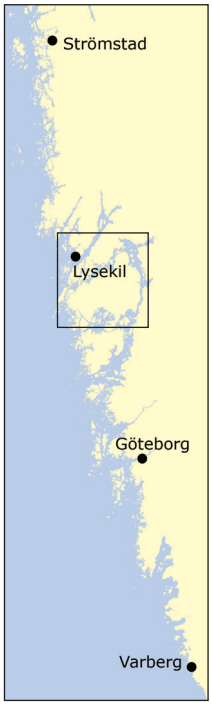


Figure 34. The highest measured value each week is presented with a specific colour. 160 μg·kg^{-1} is the regulatory maximum residue limit.

3.12. Koljö fjord

Water body Koljö fjord 581260-113220



Sampling in Koljö fjord started regularly in 1990. The upper graph shows the variation of DST during all the measured years. Some of the years show very low values, even below the regulatory maximum residue limit (160 µg·kg^{-1}), and some year very high levels. The highest level measured is about 2000 µg·kg^{-1} in winter 2000-2001. Before autumn 1998 there were only two samplings above the regulatory maximum residue limit. After this period we have the same pattern as on other places along the west coast of Sweden. The graph in the middle shows the distribution of DST values during the seasonal month of the year and the pattern clearly shows that high DST values are an autumn-winter problem. The same pattern is shown in the bottom graph but in another way. The highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

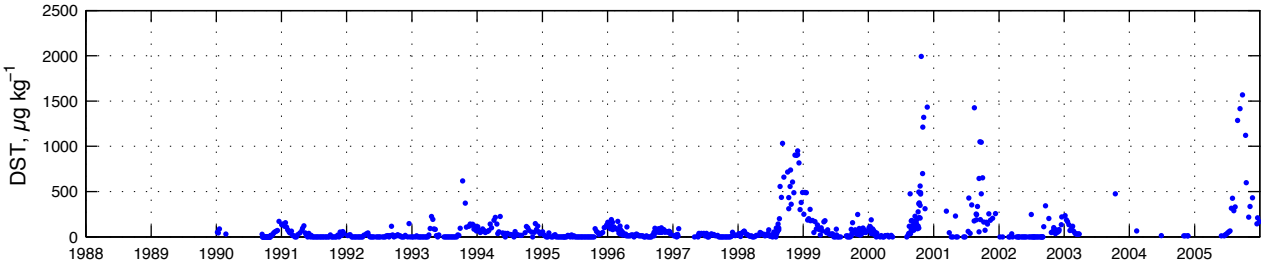


Figure 35. All measurements of DST (µg·kg^{-1}) in Koljö fjord from 1988 to 2005.

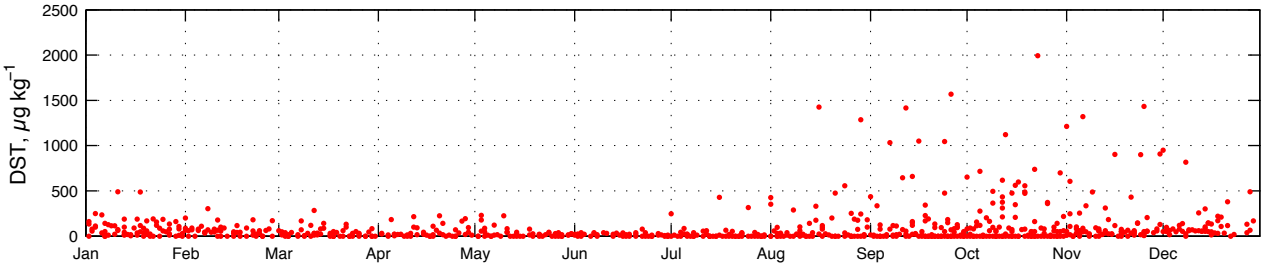


Figure 36. All measurements of DST (µg·kg^{-1}) in Koljö fjord from 1988 to 2005 presented during a year-scale.

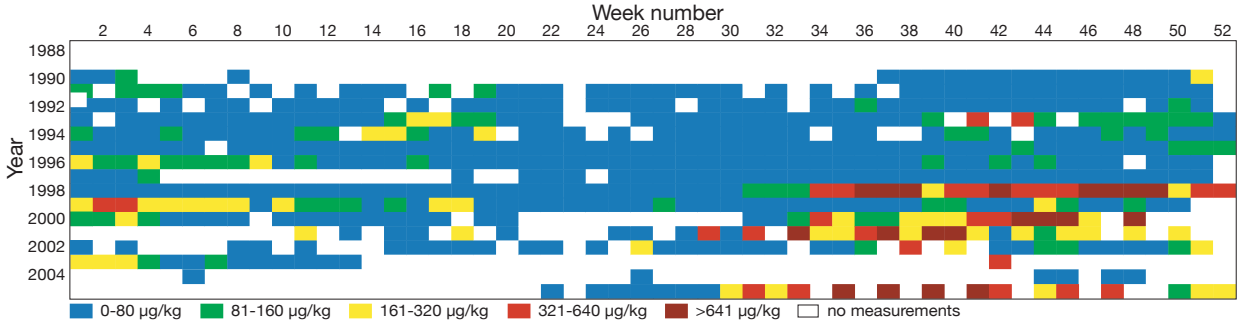
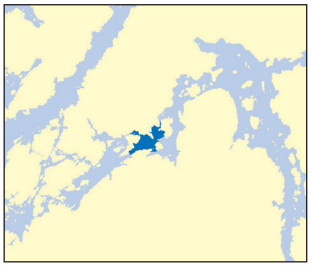
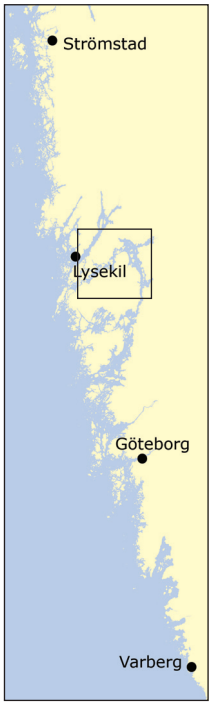


Figure 37. The highest measured value each week is presented with a specific colour. 160 µg·kg^{-1} is the regulatory maximum residue limit.

3.13. Borgilefjorden

Water body Borgilefjorden 581520-113750





Sampling in Borgilefjorden started regularly in 2001. The upper graph shows the variation of DST during all the measured years. The highest level measured is about 1500 µg·kg^{-1} in autumn 2003. The graph in the middle shows the distribution of DST values during the seasonal month of the year. In the bottom graph the highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

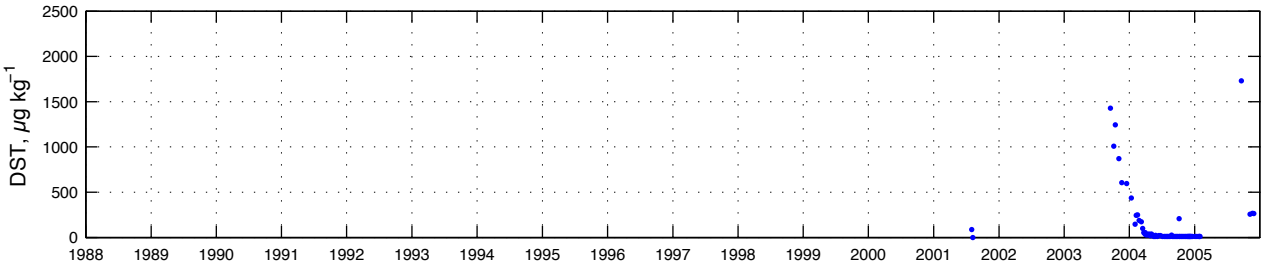


Figure 38. All measurements of DST (μg·kg^{-1}) in Borgilefjorden from 1988 to 2005.

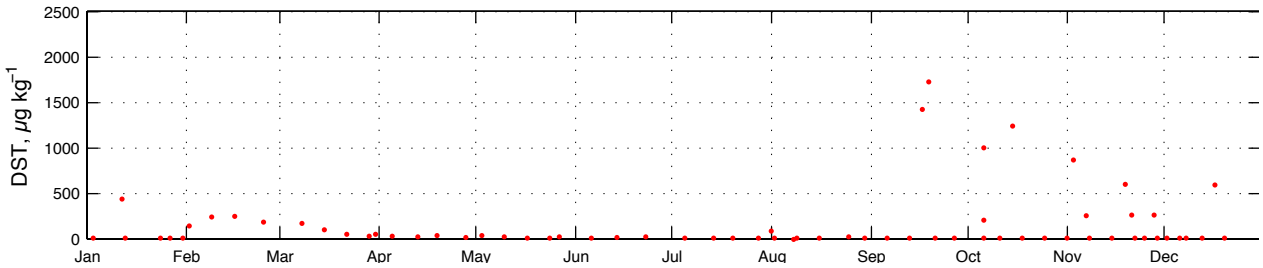


Figure 39. All measurements of DST (μg·kg^{-1}) in Borgilefjorden from 1988 to 2005 presented during a year-scale.

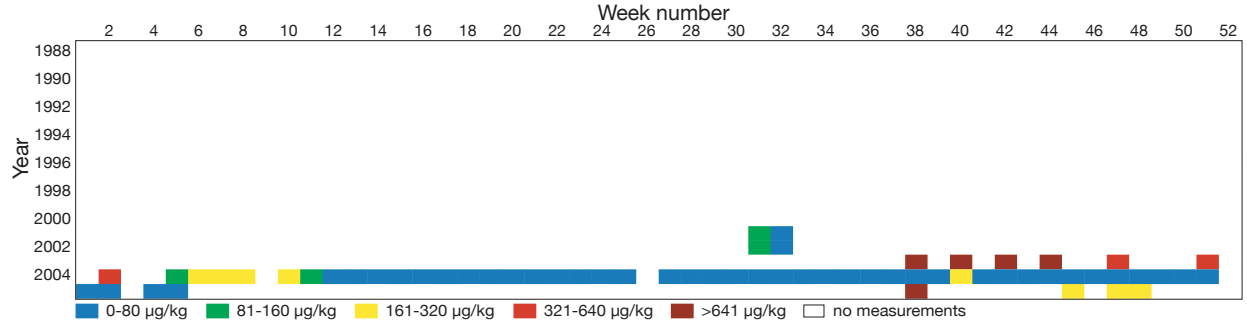
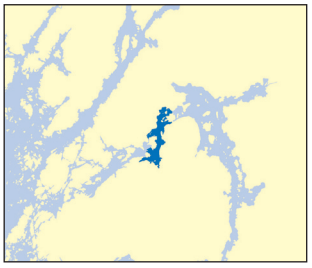
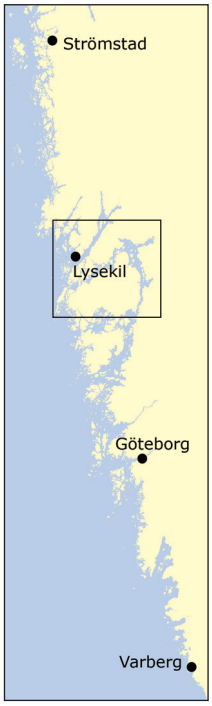


Figure 40. The highest measured value each week is presented with a specific colour. 160 μg·kg^{-1} is the regulatory maximum residue limit.

3.14. Kalvöfjord

Water body Kalvöfjord 581540-114000





Sampling in Kalvöfjord started regularly in 2000. The upper graph shows the variation of DST during all the measured years. The highest level measured is just above 500 µg·kg^{-1} in winter 2000. The graph in the middle shows the distribution of DST values during the seasonal month of the year. In the bottom graph the highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

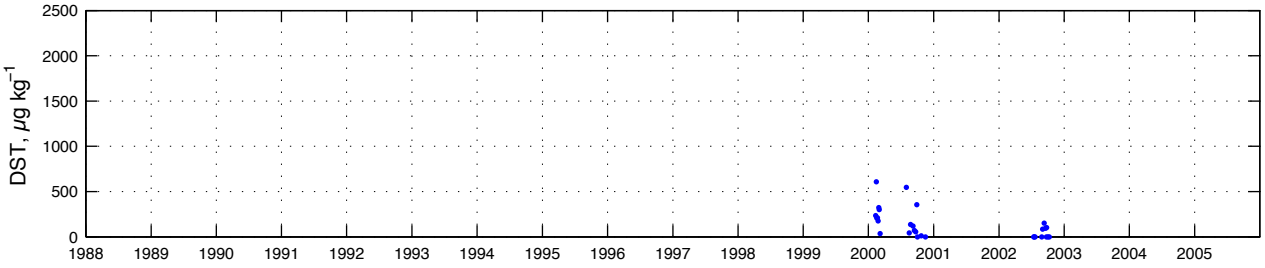


Figure 41. All measurements of DST (µg·kg^{-1}) in Kalvöfjord from 1988 to 2005.

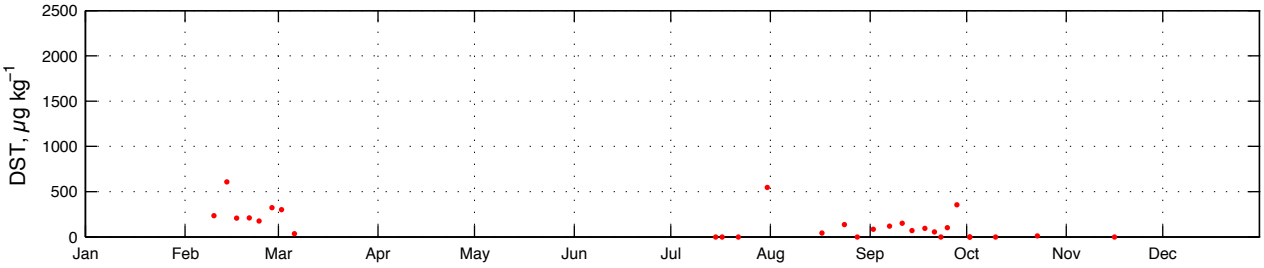


Figure 42. All measurements of DST (µg·kg^{-1}) in Kalvöfjord from 1988 to 2005 presented during a year-scale.

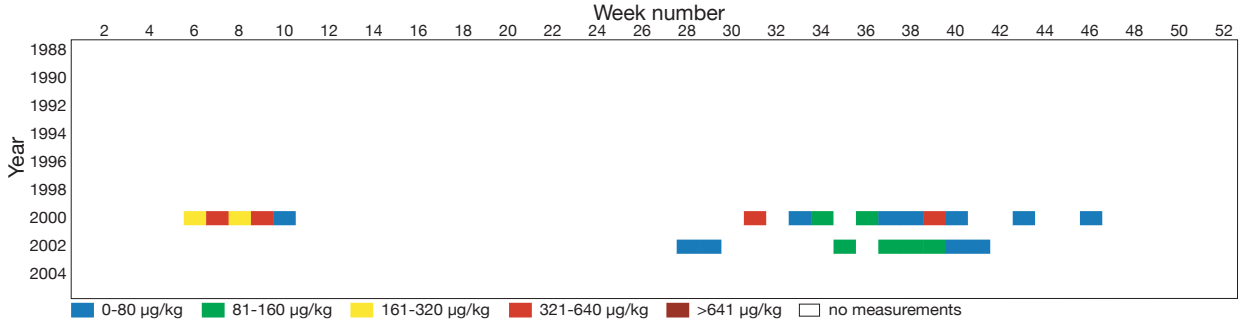
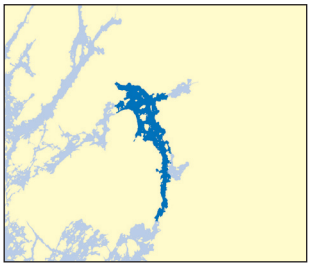
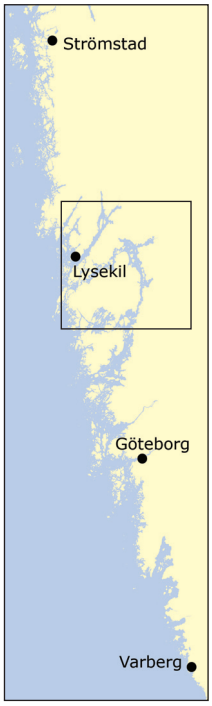


Figure 43. The highest measured value each week is presented with a specific colour. 160 µg·kg^{-1} is the regulatory maximum residue limit.

3.15. Havstensfjorden

Water body Havstensfjorden 581740-114820





Sampling in Havstensfjorden started regularly in 1994. The upper graph shows the variation of DST during all the measured years. The highest level measured is around 1500 µg·kg^{-1} in winter 1998-1999. The graph in the middle shows the distribution of DST values during the seasonal month of the year. In the bottom graph the highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

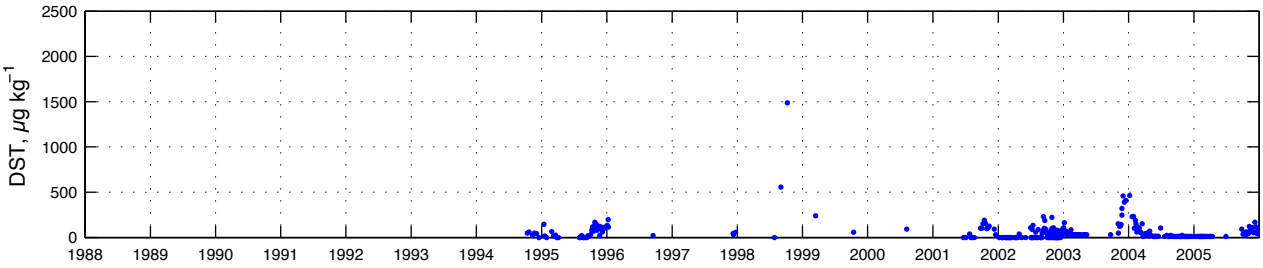


Figure 44. All measurements of DST (μg·kg^{-1}) in Havstensfjorden from 1988 to 2005.

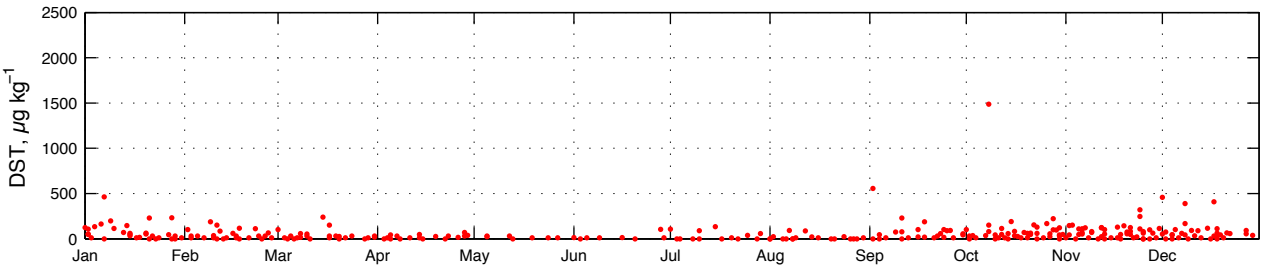


Figure 45. All measurements of DST (μg·kg^{-1}) in Havstensfjorden from 1988 to 2005 presented during a year-scale.

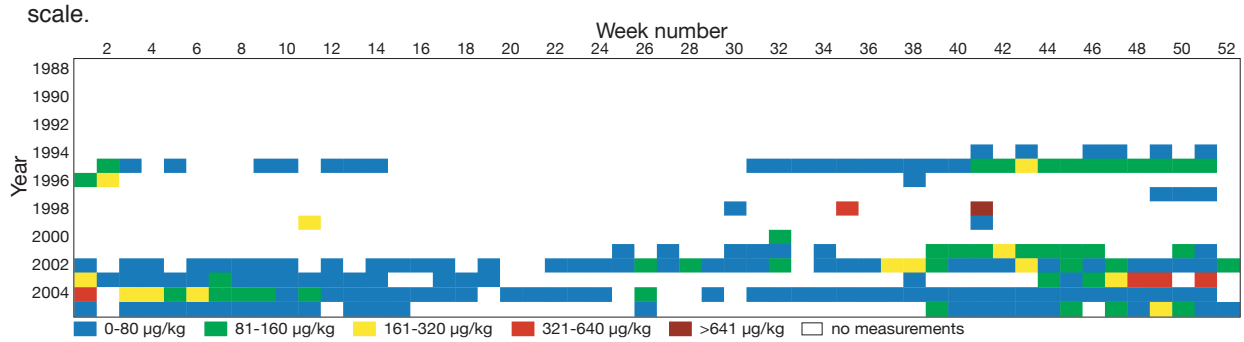
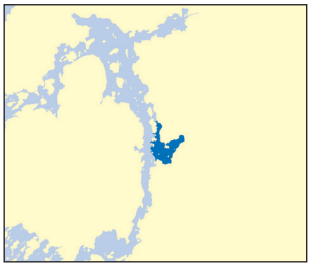
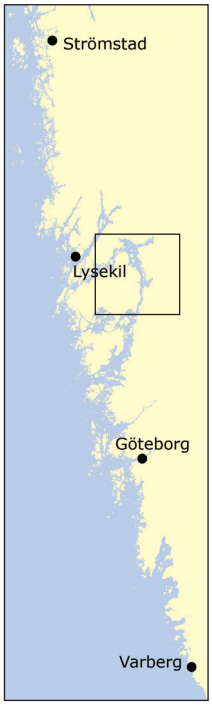


Figure 46. The highest measured value each week is presented with a specific colour. 160 μg·kg^{-1} is the regulatory maximum residue limit.

3.16. Ljungskile

Water body Ljungskile 581260-115280





Sampling in Ljungskile started regularly in 1997. The upper graph shows the variation of DST during all the measured years. Some of the years show very low values, even below the regulatory maximum residue limit (160 µg·kg^{-1}), and some year very high levels. The highest level measured is about 1400 µg·kg^{-1} in winter 2000-2001. The graph in the middle shows the distribution of DST values during the seasonal month of the year and the pattern clearly shows that high DST values are an autumn-winter problem. The same pattern is shown in the bottom graph but in another way. The highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

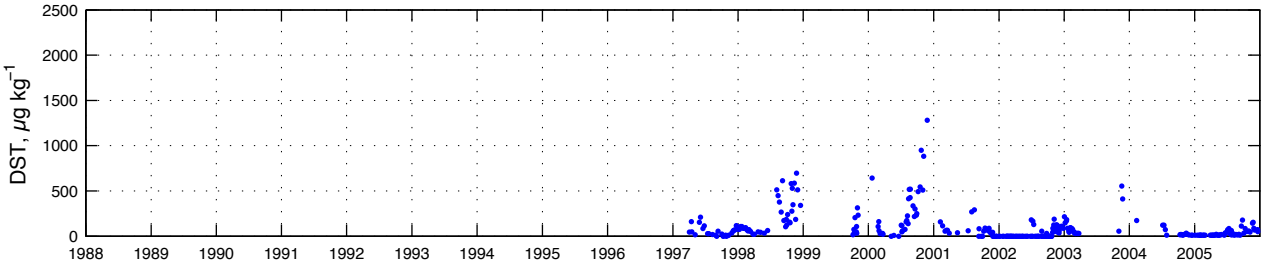


Figure 47. All measurements of DST (μg·kg^{-1}) in Ljungskile from 1988 to 2005.

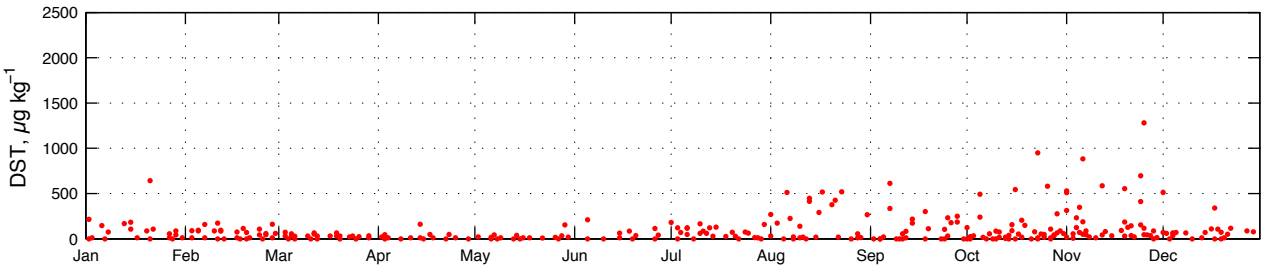


Figure 48. All measurements of DST (μg·kg^{-1}) in Ljungskile from 1988 to 2005 presented during a year-scale.

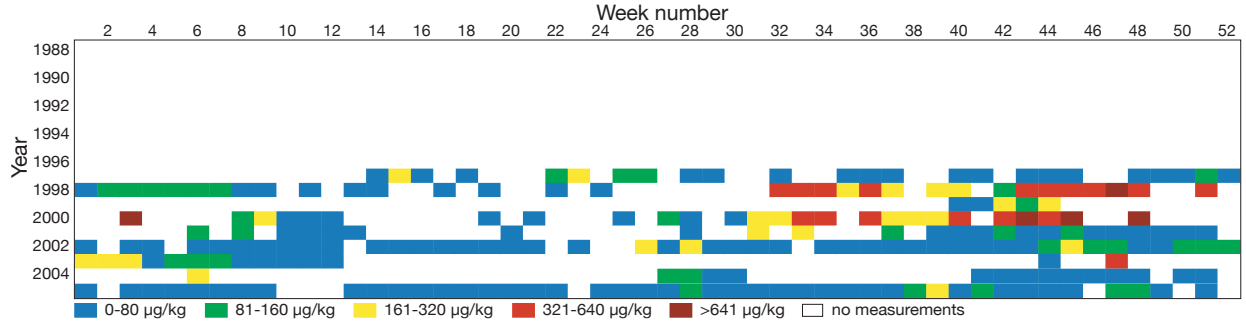
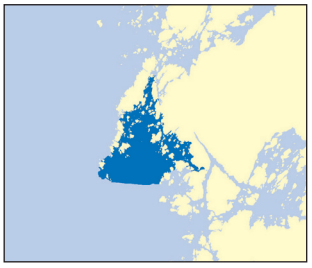
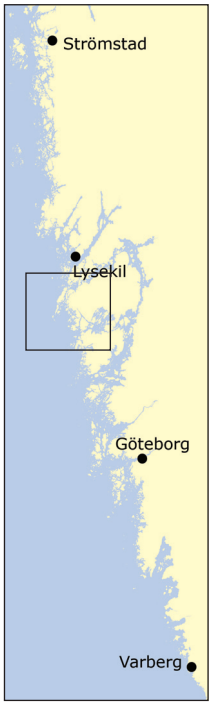


Figure 49. The highest measured value each week is presented with a specific colour. 160 μg·kg^{-1} is the regulatory maximum residue limit.

3.17. Käringöfjorden

Water body Käringöfjorden 580550-112460





There is only one sample taken in Käringöfjorden and it is from 1999. The upper graph shows the variation of DST during all the measured years. The graph in the middle shows the distribution of DST values during the seasonal month of the year. In the bottom graph the highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

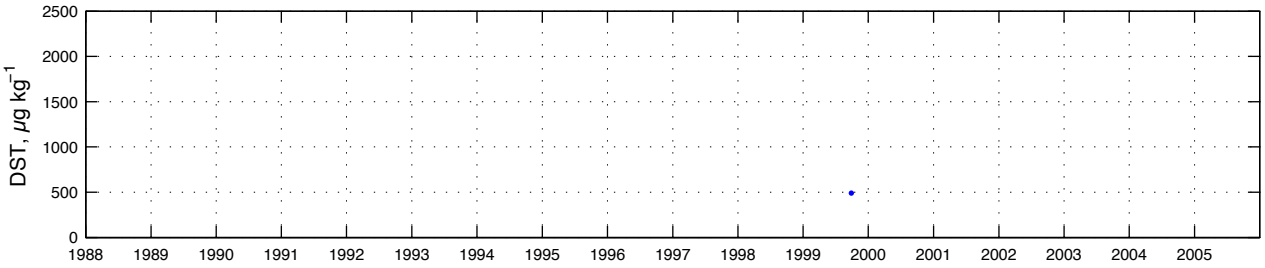


Figure 50. All measurements of DST ($\mu g \cdot kg^{-1}$) in Käringöfjorden from 1988 to 2005.

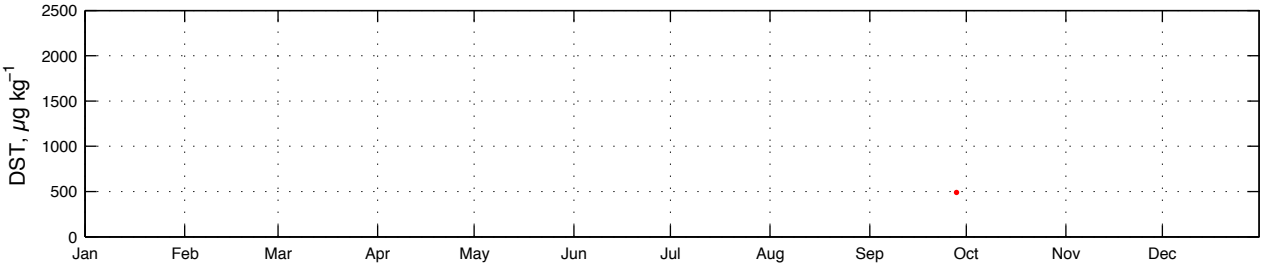


Figure 51. All measurements of DST ($\mu g \cdot kg^{-1}$) in Käringöfjorden from 1988 to 2005 presented during a year-scale.

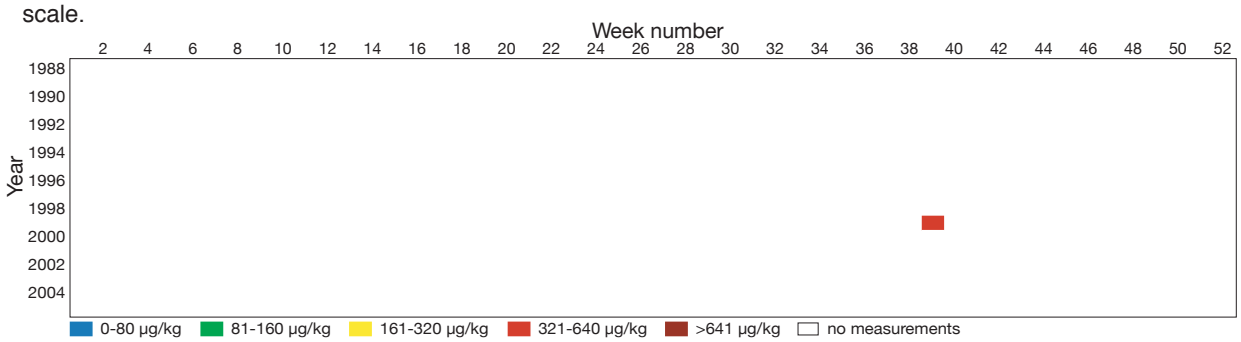
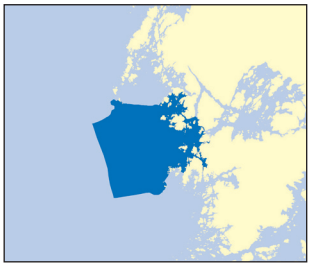
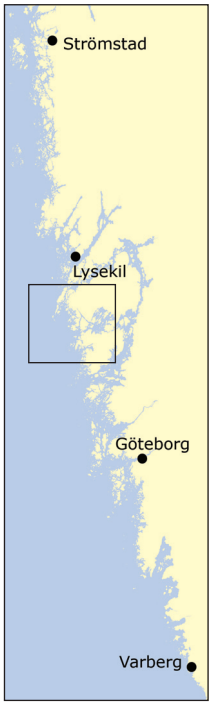


Figure 52. The highest measured value each week is presented with a specific colour. 160 $\mu g \cdot kg^{-1}$ is the regulatory maximum residue limit.

3.18. Mollöfjorden

Water body Mollöfjorden 580240-112501





Sampling in Mollöfjorden started regularly in 1999. The upper graph shows the variation of DST during all the measured years. The highest level measured is just below 1000 µg·kg^{-1} in winter 1999-2000. The graph in the middle shows the distribution of DST values during the seasonal month of the year and the pattern shows that high DST values are an autumn-winter problem but high DST-values may also occur in June, July and August. The same pattern is shown in the bottom graph but in another way. The highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

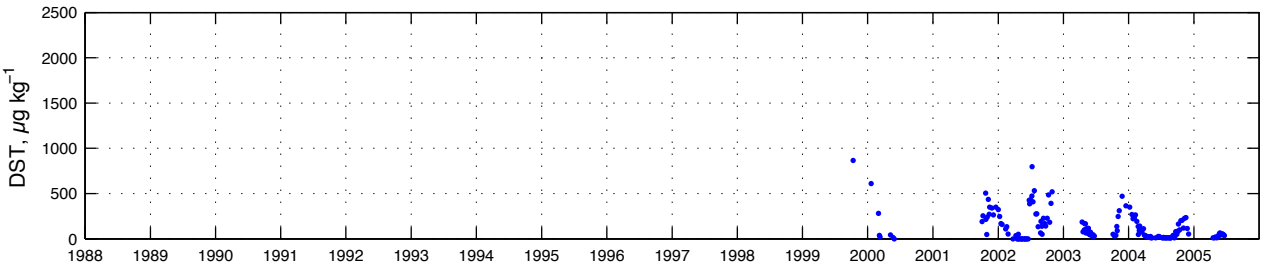


Figure 53. All measurements of DST (µg·kg^{-1}) in Mollöfjorden from 1988 to 2005.

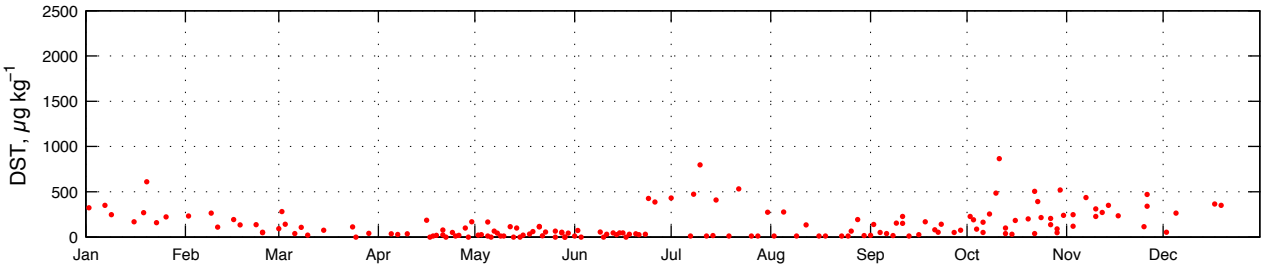


Figure 54. All measurements of DST (µg·kg^{-1}) in Mollöfjorden from 1988 to 2005 presented during a year-scale.

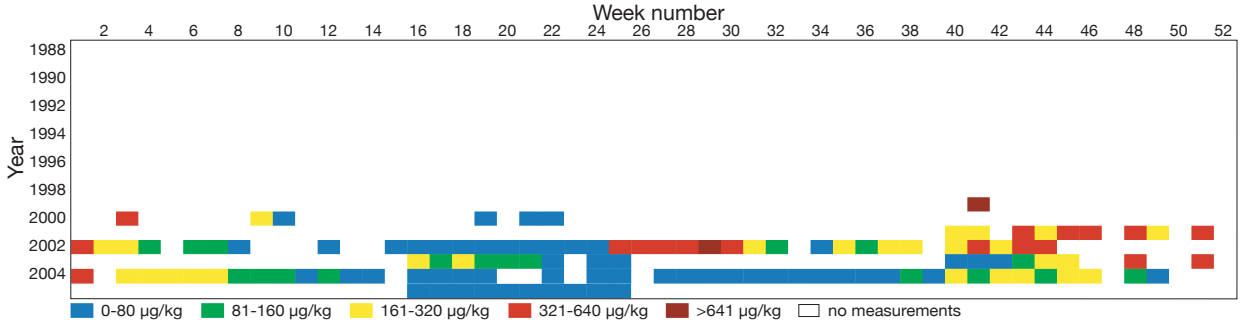
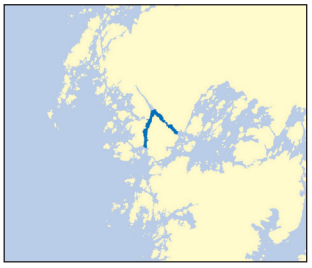
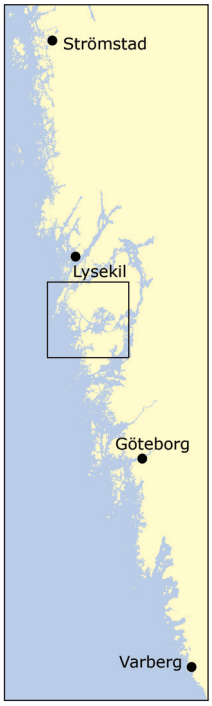


Figure 55. The highest measured value each week is presented with a specific colour. 160 µg·kg^{-1} is the regulatory maximum residue limit.

3.19. Lyresund

Water body Lyresund 580500-112970





Sampling in Lyresund started regularly in 1995. The upper graph shows the variation of DST during all the measured years. The highest level measured is just above 1000 µg·kg^{-1} in winter 2002-2003. The graph in the middle shows the distribution of DST values during the seasonal month of the year and the pattern clearly shows that high DST values are an autumn-winter problem. The same pattern is shown in the bottom graph but in another way. The highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

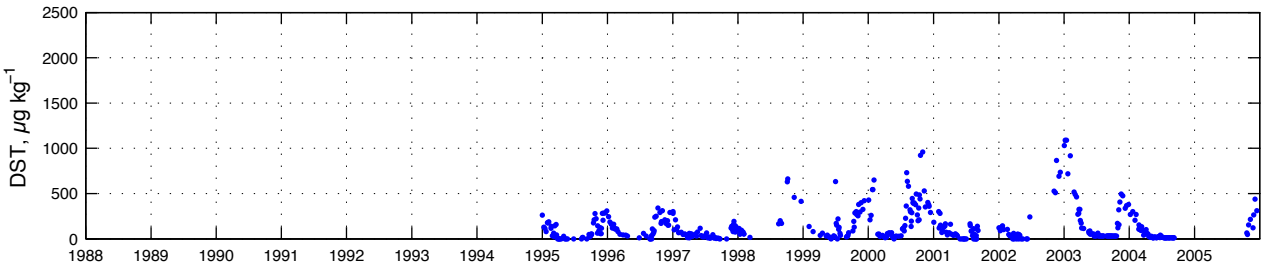


Figure 56. All measurements of DST (μg·kg^{-1}) in Lyrösund from 1988 to 2005.

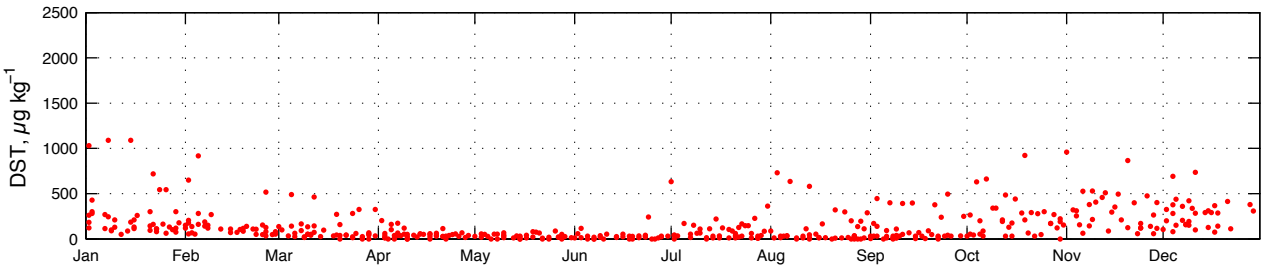


Figure 57. All measurements of DST (μg·kg^{-1}) in Lyrösund from 1988 to 2005 presented during a year-scale.

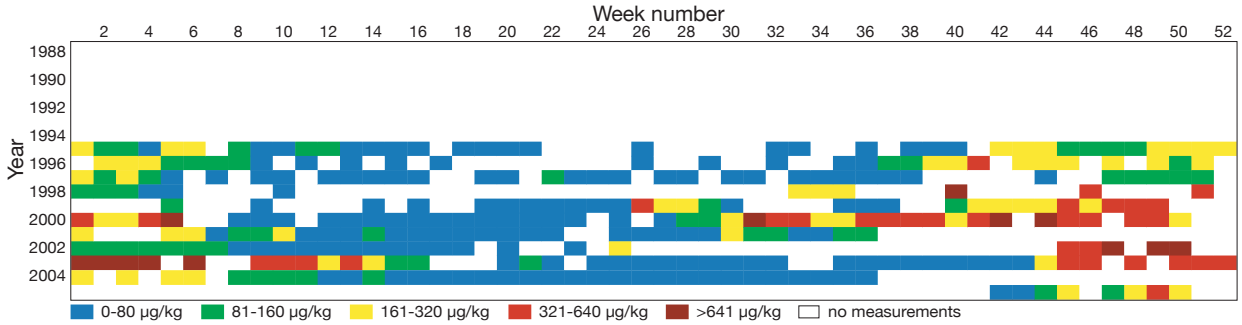
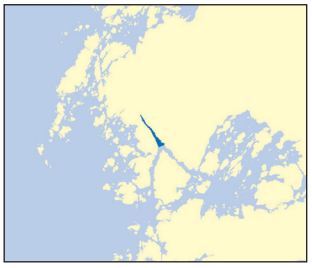


Figure 58. The highest measured value each week is presented with a specific colour. 160 μg·kg^{-1} is the regulatory maximum residue limit.

3.20. Boxvike kile

Water body Boxvike kile 580650-113000



Sampling in Boxvike kile started regularly in 1988. The upper graph shows the variation of DST during all the measured years. After 1994 is the data more sporadic. The highest level measured is just above 2000 µg·kg^{-1} in winter 1989-1990. The graph in the middle shows the distribution of DST values during the seasonal month of the year and the pattern clearly shows that high DST values are an autumn-winter problem. The same pattern is shown in the bottom graph but in another way. The highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

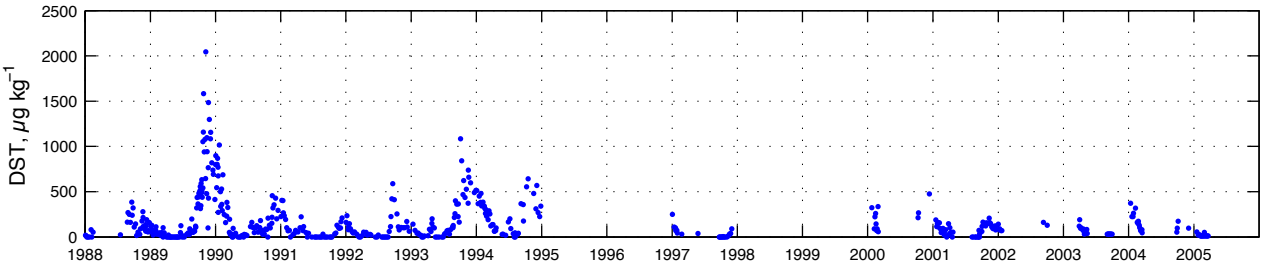


Figure 59. All measurements of DST (μg·kg^{-1}) in Boxevike kile from 1988 to 2005.

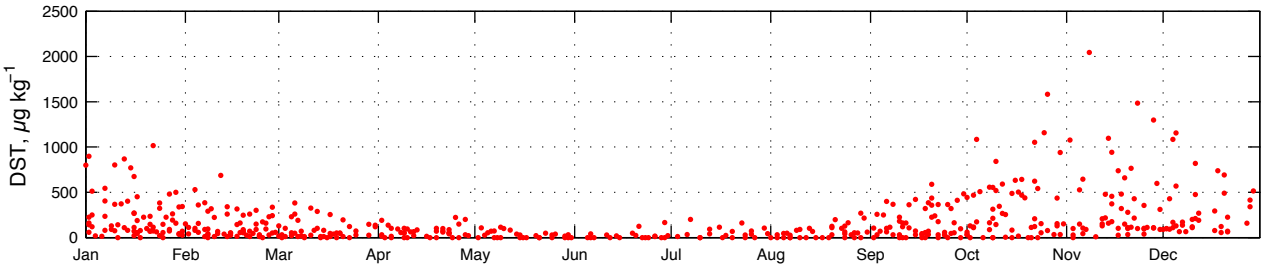


Figure 60. All measurements of DST (μg·kg^{-1}) in Boxevike kile from 1988 to 2005 presented during a year-scale.

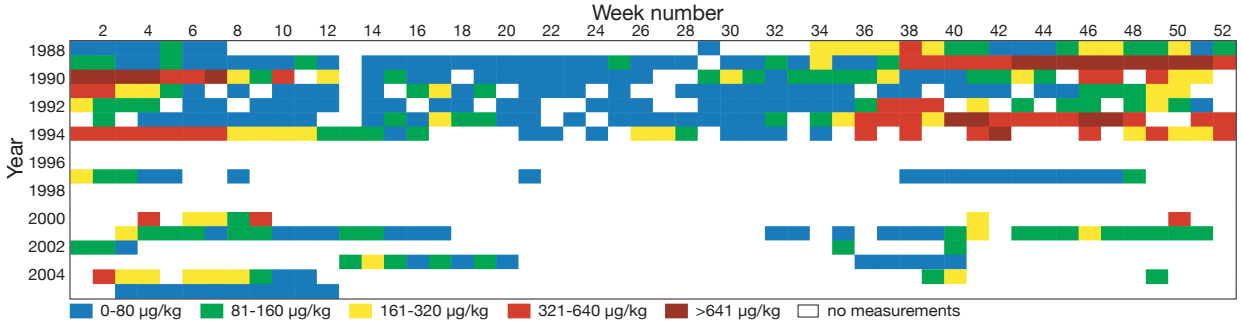
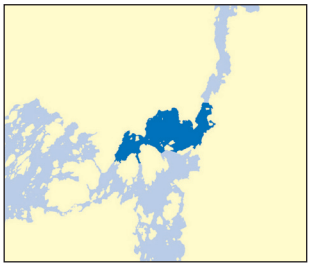
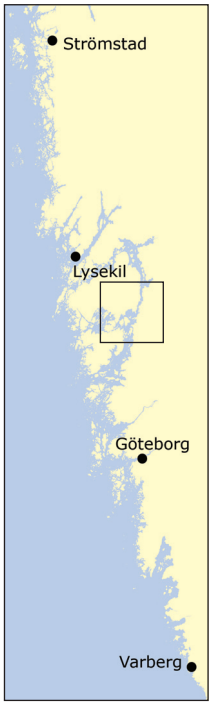


Figure 61. The highest measured value each week is presented with a specific colour. 160 μg·kg^{-1} is the regulatory maximum residue limit.

3.21. Halsefjorden

Water body Halsefjorden 580688-114860





Sampling in Halsefjorden started regularly in 1989. The upper graph shows the variation of DST during all the measured years. The highest level measured is around 2500 µg·kg^{-1} in winter 1998-1999. The graph in the middle shows the distribution of DST values during the seasonal month of the year and the pattern clearly shows that high DST values are an autumn-winter problem. The same pattern is shown in the bottom graph but in another way. The highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

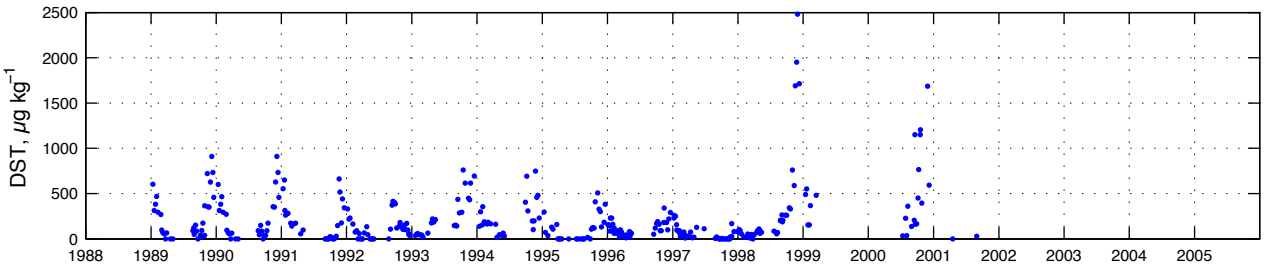


Figure 62. All measurements of DST (µg·kg^{-1}) in Halsefjorden from 1988 to 2004.

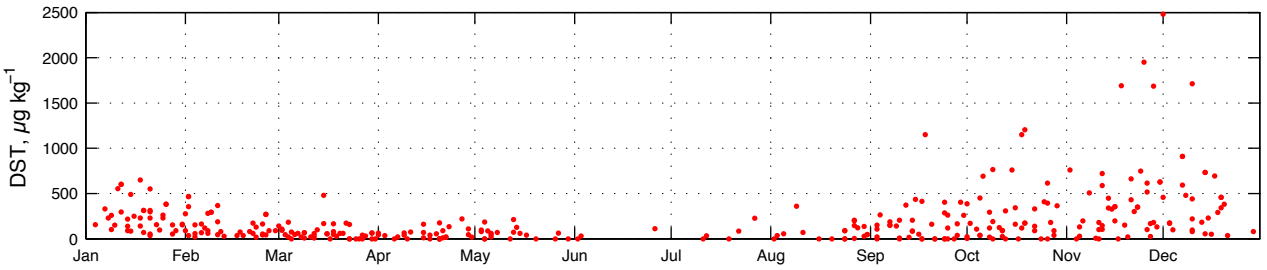


Figure 63. All measurements of DST (µg·kg^{-1}) in Halsefjorden from 1988 to 2004 presented during a year-scale.

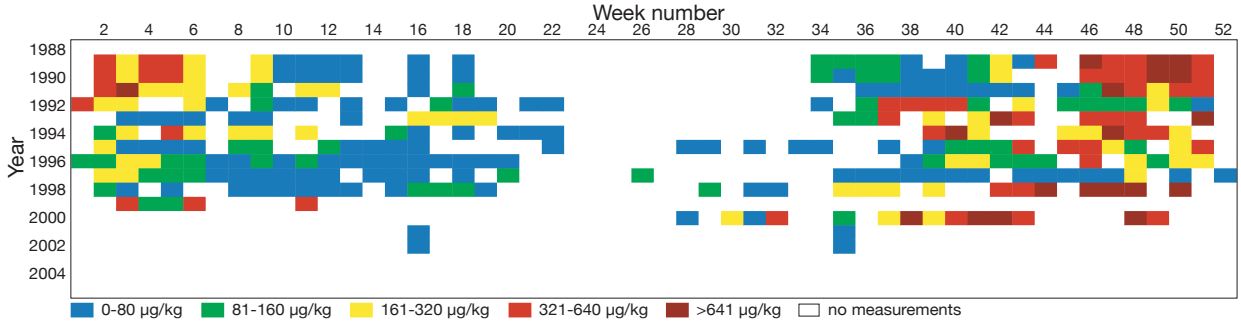
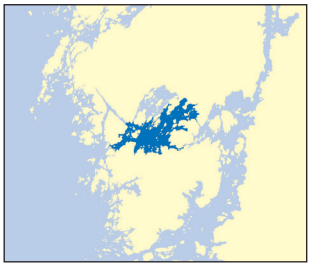
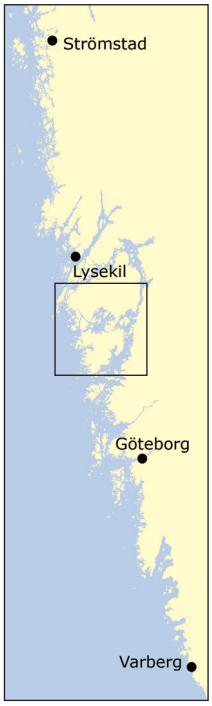


Figure 64. The highest measured value each week is presented with a specific colour. 160 µg·kg^{-1} is the regulatory maximum residue limit.

3.22. Stigfjorden

Water body Stigfjorden 580325-113500





Sampling in Stigfjorden started regularly in 1996. The upper graph shows the variation of DST during all the measured years. The highest level measured is around 600 µg·kg^{-1} in winter 1999-2000 and 2002-2003. The graph in the middle shows the distribution of DST values during the seasonal month of the year and the pattern clearly shows that high DST values are an autumn-winter problem. The same pattern is shown in the bottom graph but in another way. The highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

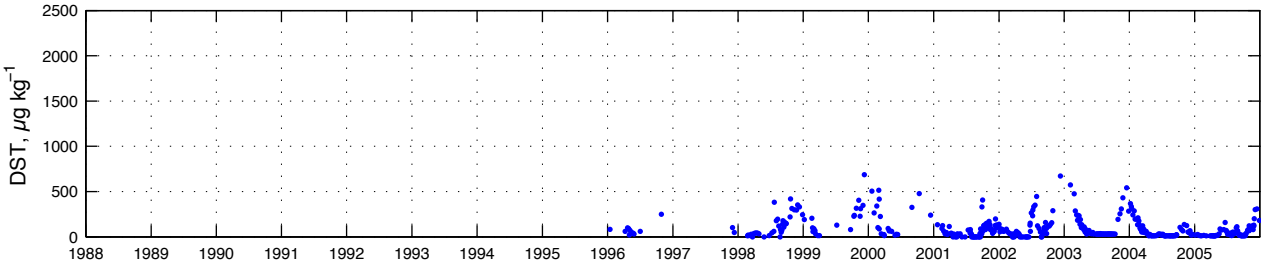


Figure 65. All measurements of DST (µg·kg^{-1}) in Stigfjorden from 1988 to 2005.

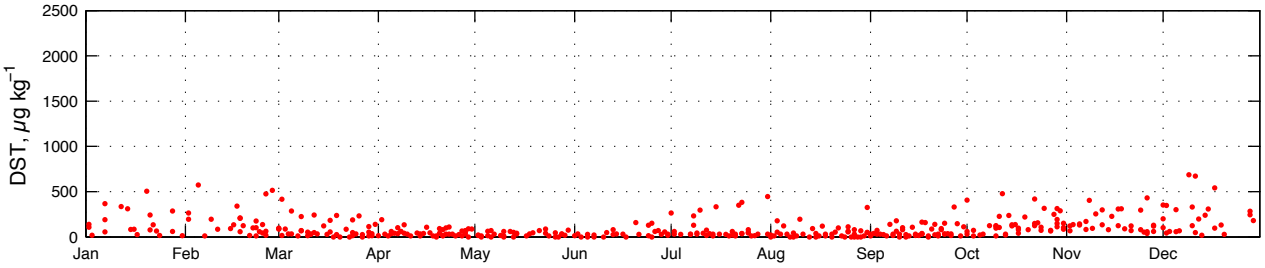


Figure 65. All measurements of DST (µg·kg^{-1}) in Stigfjorden from 1988 to 2005 presented during a year-scale.

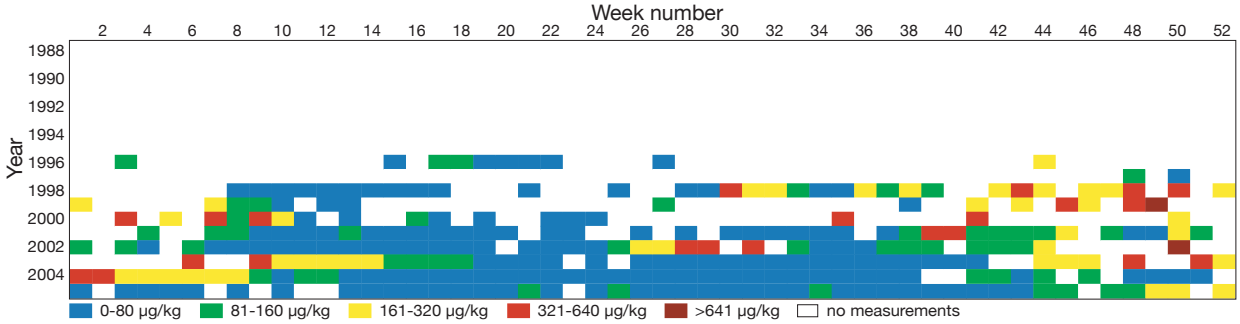
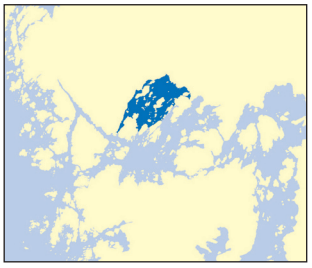
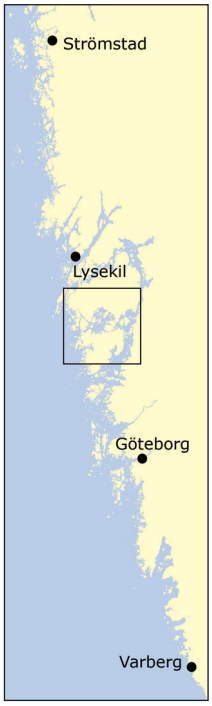


Figure 67. The highest measured value each week is presented with a specific colour. 160 µg·kg^{-1} is the regulatory maximum residue limit.

3.23. Kalvöfjorden

Water body Kalvöfjorden 580610-113615





There are only three samples totally from Kalvöfjorden and they are from year 2000. The upper graph shows the variation of DST during all the measured years. The graph in the middle shows the distribution of DST values during the seasonal month of the year. In the bottom graph the highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

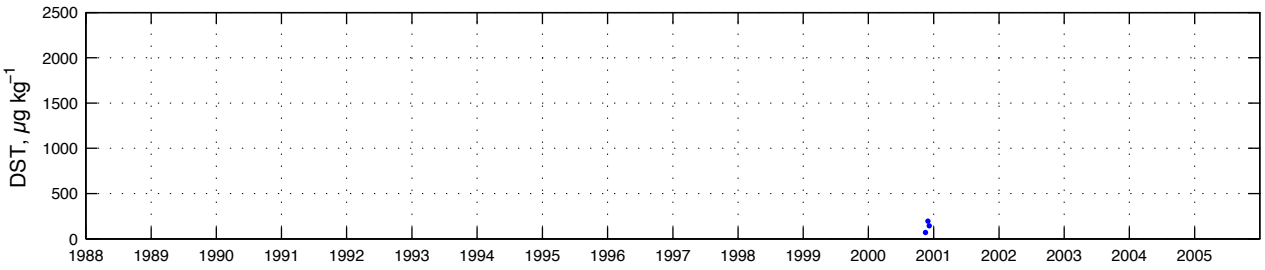


Figure 68. All measurements of DST ($\mu g \cdot kg^{-1}$) in Kalvöfjorden from 1988 to 2005.

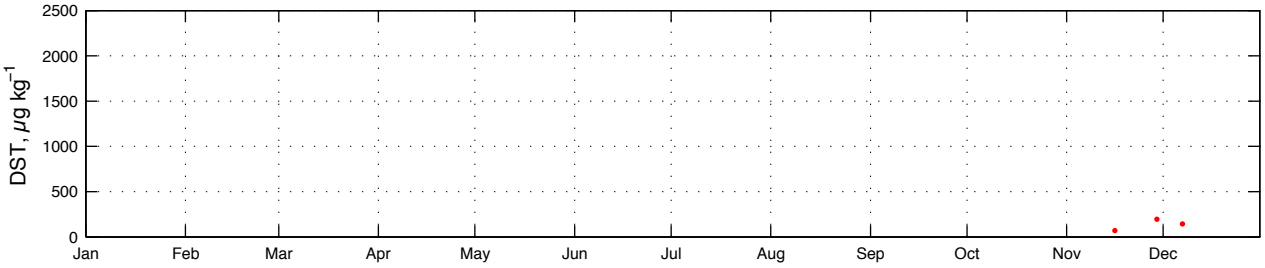


Figure 69. All measurements of DST ($\mu g \cdot kg^{-1}$) in Kalvöfjorden from 1988 to 2005 presented during a year-scale.

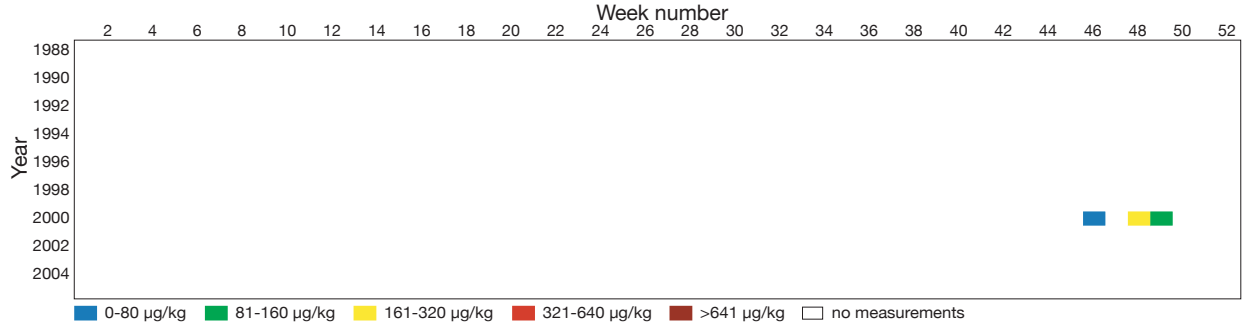
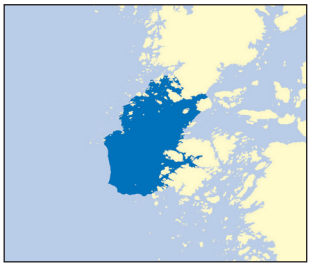
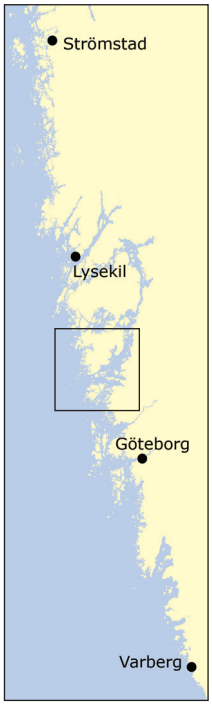


Figure 70. The highest measured value each week is presented with a specific colour. 160 $\mu g \cdot kg^{-1}$ is the regulatory maximum residue limit.

3.24. Marstrandsfjorden

Water body Marstrandsfjorden 575340-113000





In Marstrandsfjorden there are only some samples from three different years, 2001, 2002 and 2004. The upper graph shows the variation of DST during all the measured years. The graph in the middle shows the distribution of DST values during the seasonal month of the year. In the bottom graph the highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

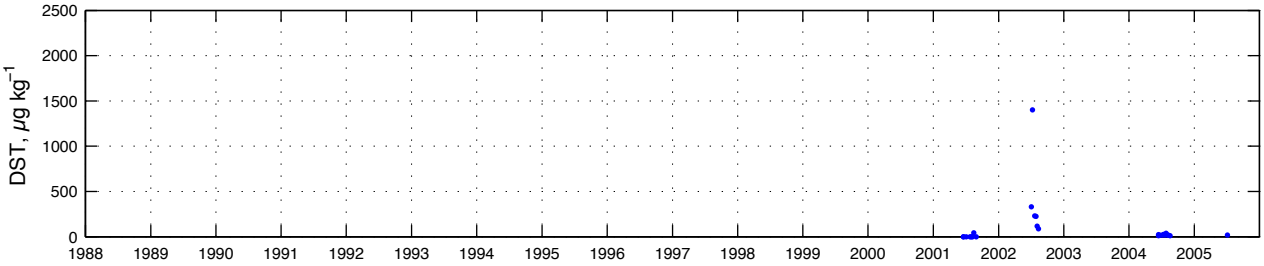


Figure 71. All measurements of DST ($\mu g \cdot kg^{-1}$) in Marstrandsfjorden from 1988 to 2005.

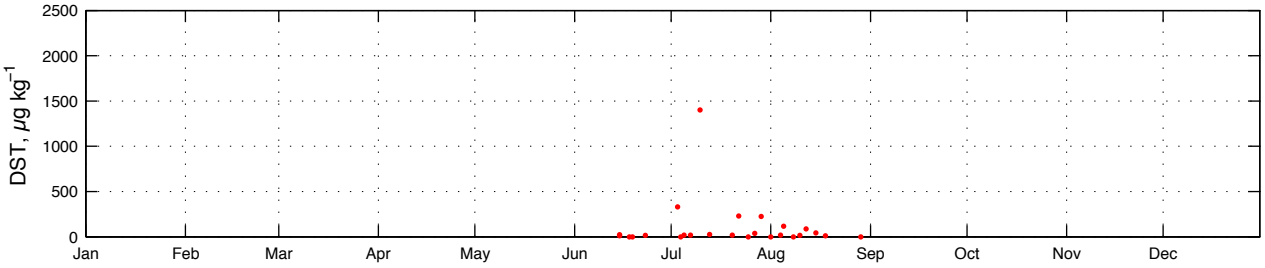


Figure 72. All measurements of DST ($\mu g \cdot kg^{-1}$) in Marstrandsfjorden from 1988 to 2005 presented during a year-scale.

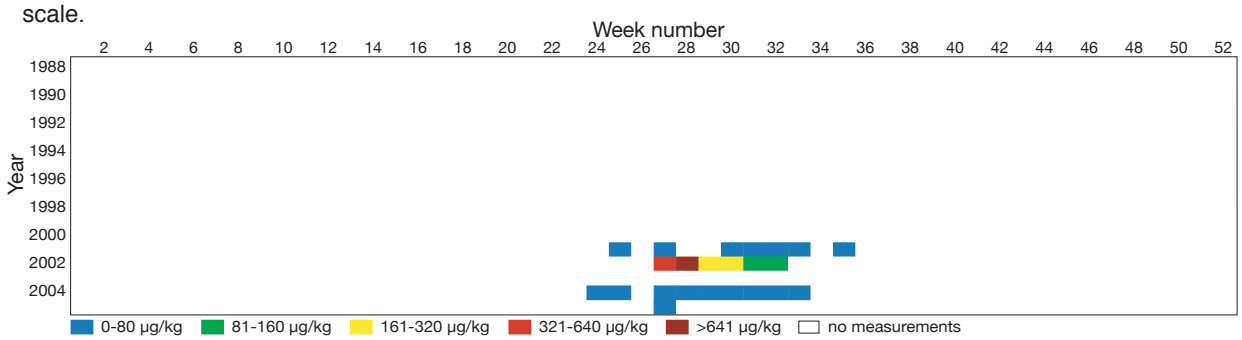
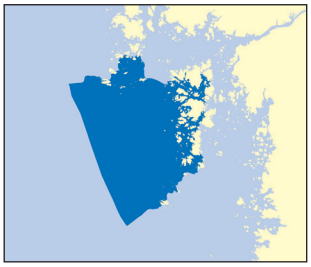
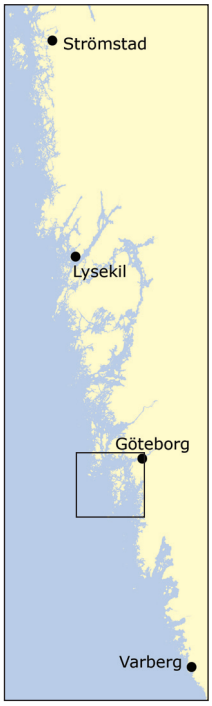


Figure 73. The highest measured value each week is presented with a specific colour. 160 $\mu g \cdot kg^{-1}$ is the regulatory maximum residue limit.

3.25. Göteborgs s skärgårds kustvatten

Water body Göteborgs s skärgårds kustvatten
573300-113801





Sampling in Göteborgs s skärgårds kustvatten started regularly in 1991. The upper graph shows the variation of DST during all the measured years. The highest level measured is from 1994 November to December with 5 values higher than 2500 and with the highest value in December on 4659 and around 1800 µg·kg^{-1} in winter 1994-1995. The graph in the middle shows the distribution of DST values during the seasonal month of the year and the pattern clearly shows that high DST values are an autumn-winter problem. The same pattern is shown in the bottom graph but in another way. The highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

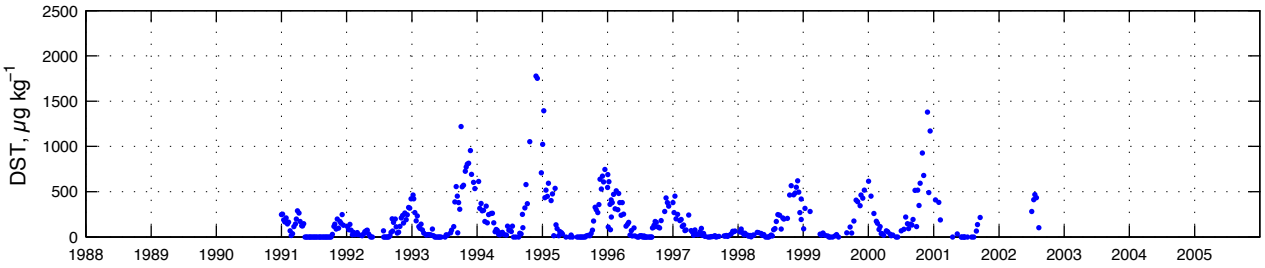


Figure 74. All measurements of DST (µg·kg^{-1}) in Göteborgs s skärgårds kustvatten from 1988 to 2005.

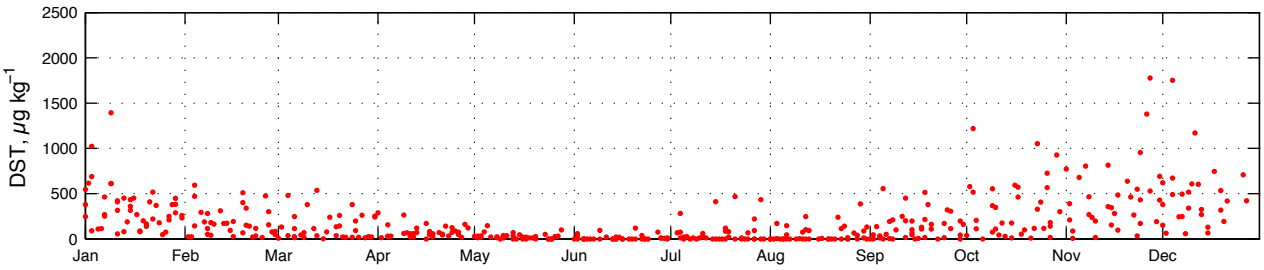


Figure 75. All measurements of DST (µg·kg^{-1}) in Göteborgs s skärgårds kustvatten from 1988 to 2005 presented during a year-scale.

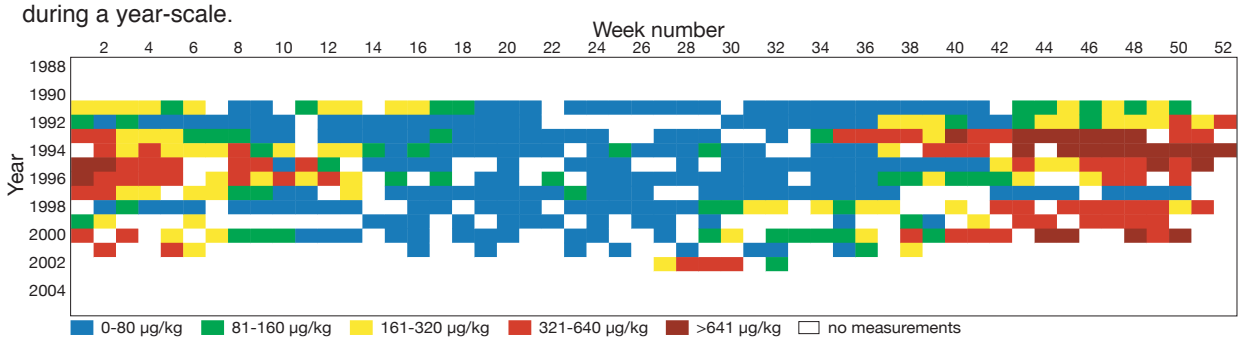
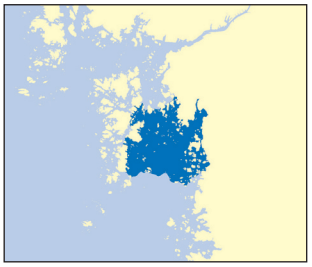


Figure 76. The highest measured value each week is presented with a specific colour. 160 µg·kg^{-1} is the regulatory maximum residue limit.

3.26. Askims fjord

Water body Askims fjord 573500-115150



Sampling in Askims fjord started regularly in 1993. Most of the measurements have been performed in the summer periods. The upper graph shows the variation of DST during all the measured years. The graph in the middle shows the distribution of DST values during the seasonal month of the year. In the bottom graph the highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

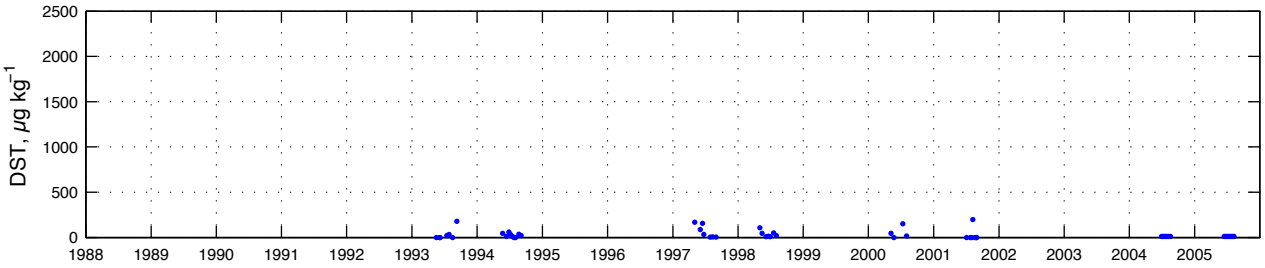


Figure 77. All measurements of DST ($\mu g \cdot kg^{-1}$) in Askims fjord from 1988 to 2005.

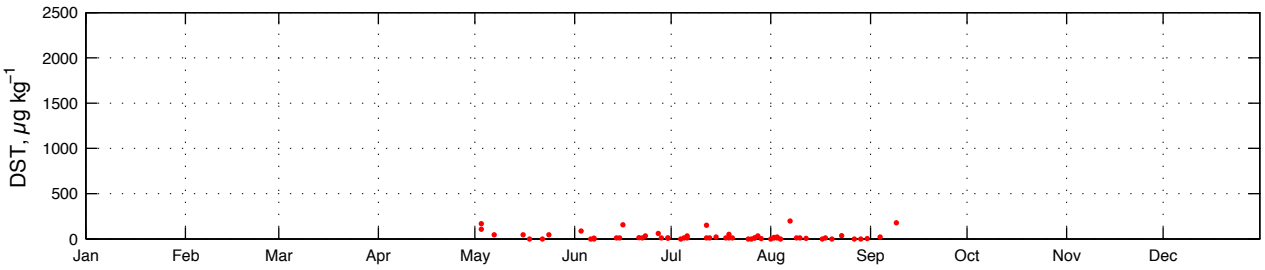


Figure 78. All measurements of DST ($\mu g \cdot kg^{-1}$) in Askims fjord from 1988 to 2005 presented during a year-scale.

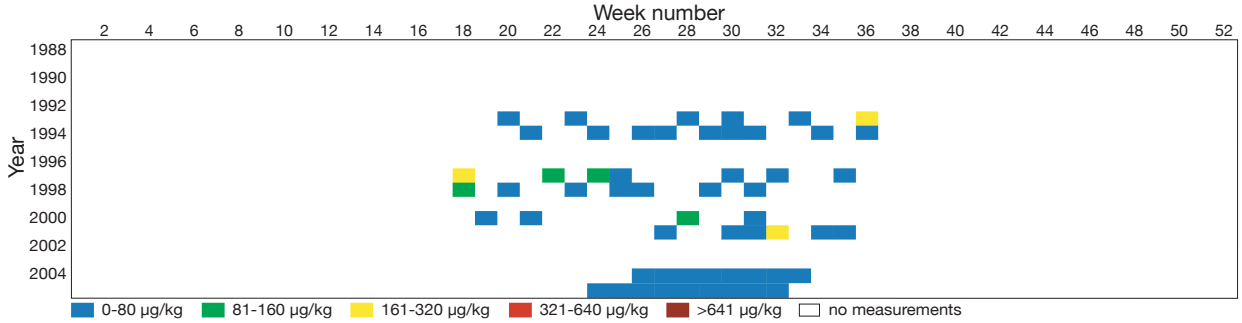
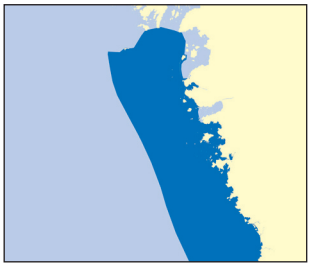


Figure 79. The highest measured value each week is presented with a specific colour. 160 $\mu g \cdot kg^{-1}$ is the regulatory maximum residue limit.

3.27. N m Hallands kustvatten

Water body N m Hallands kustvatten 570000-120701



Sampling in N m Hallands kustvatten started in 1994 and finished in 1995. Most of the measurements have been performed in the summer periods. The upper graph shows the variation of DST during all the measured years. The graph in the middle shows the distribution of DST values during the seasonal month of the year. In the bottom graph the highest measured value each week is presented with a specific colour. The blue and green colour shows DST values below the regulatory maximum residue limit.

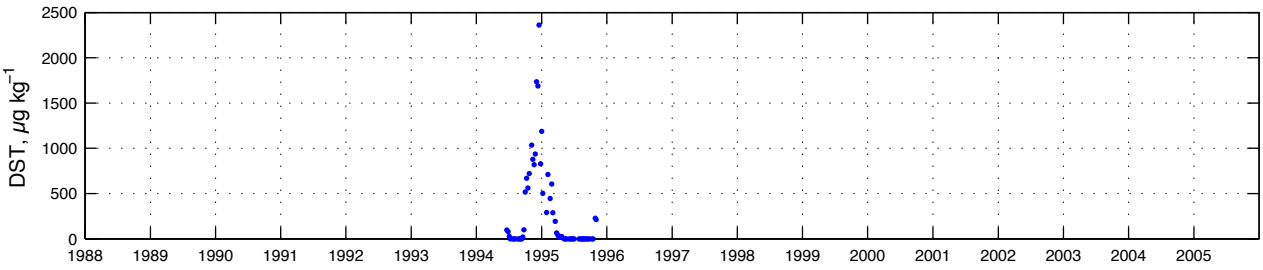


Figure 80. All measurements of DST ($\mu g \cdot kg^{-1}$) in N m Hallands kustvatten from 1988 to 2005.

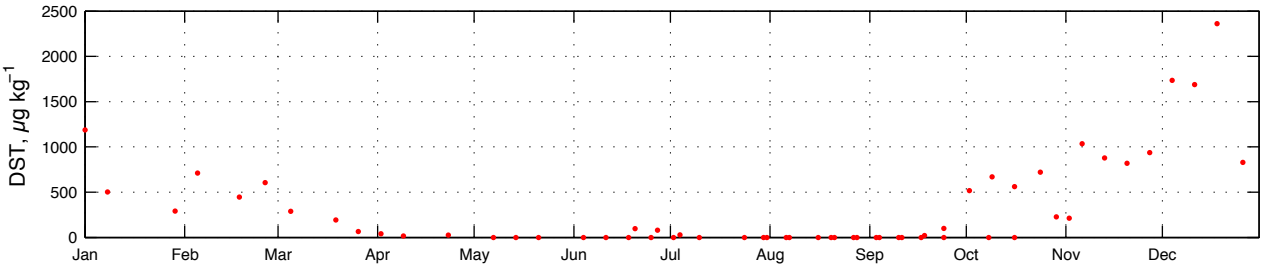


Figure 81. All measurements of DST ($\mu g \cdot kg^{-1}$) in N m Hallands kustvatten from 1988 to 2005 presented during a year-scale.

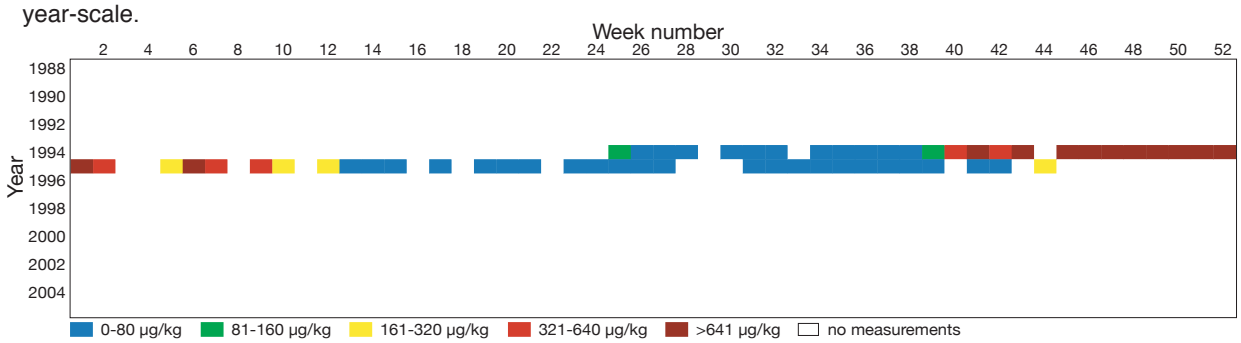


Figure 82. The highest measured value each week is presented with a specific colour. 160 $\mu g \cdot kg^{-1}$ is the regulatory maximum residue limit.

4 Discussion

4.1 Temporal and spatial distribution of DST

In Western Europe it is traditional to say that shellfish can be safely consumed in "months with r", *i.e.* September-April. This is also "common knowledge" for the average Swede. Our data clearly show that the general risk of DSP in Sweden is highest during the period August to March. These results clearly show that there is no link between the r- rule and DSP occurrence. It is more likely to assume that this rule comes from the experiences of consumption of mussels contaminated by human pathogens. It should also be pointed out that *Mytilus edulis* at higher latitudes shows a pronounced annual cycle of reproduction and usually starts to spawn in April which continues until early summer (Loo & Rosenberg 1983). This means that during that time of the year the blue mussels on the Swedish coastline are low in flesh and stressed by higher temperature in the water, and therefore not ideal for consumption.

Here we report that toxin patterns can differ significantly both due to location and year (also observed by Lindegarth 1997). In a study by Ramstad *et al.* performed in February to mid October 1997 (Ramstad *et al.* 2001), a clear monthly variation in toxicity could be recorded from the coast to the inner part of Sognefjord, Norway. The concentration of DST increased with distance to the coast and the highest concentration, 349 µg OA equivalents·100 g^{-1} mussel meat (analysed by a colorimetric protein phosphatase inhibition assay) was measured in August. Toxin levels fluctuate significantly in the Swedish Tjärnö archipelago and mussels can become toxic within days, which was clearly shown in a study by Godhe *at el.* (2002). During the period October 10 to November 5 year 2000, three distinct water masses passed through the vicinity of the mussel farm in the area. The second water mass contained a high abundance of *Dinophysis* spp., high concentrations of DST in the phytoplankton population, and a subsequent rapid increase (within two days) in the toxicity of mussels was observed. After 8 days, the water mass containing *Dinophysis* was replaced and cell numbers again returned to low levels. However, the toxicity of mussels continued to be high for the remainder of the study. This rapid intoxication vs. slow detoxification of mussels is a common phenomenon in Swedish waters (Svensson *et al.* 2003). In the major mussel farming area in Sweden, the Lysekil/Boxvike kile region, farmers have experienced nearly toxin free years, but up to 26 consecutive weeks of high toxin levels have also been recorded. Fortunately for the industry, there are usually some regions with toxin concentrations below the maximum residue limit and the mussel farmers can usually manage to supply the market with mussels by harvesting from different locations.

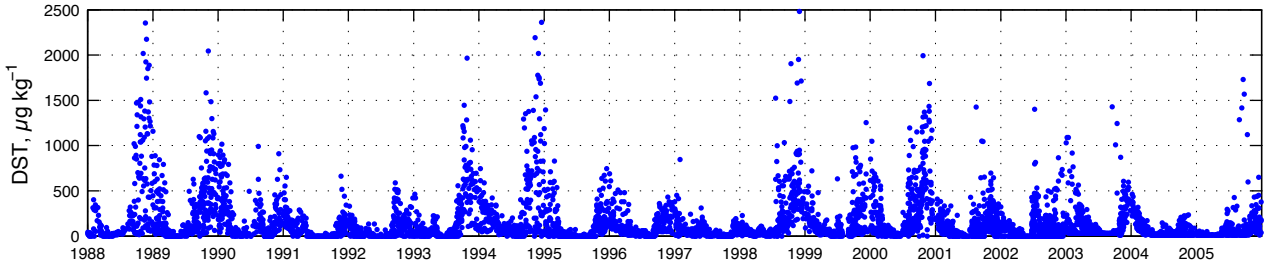


Figure 83. All measurements of DST (µg·kg^{-1}) at all locations from 1988 to 2005. Five data points from November-December 1994 are off scale. The highest value was 4659 in December 1994.

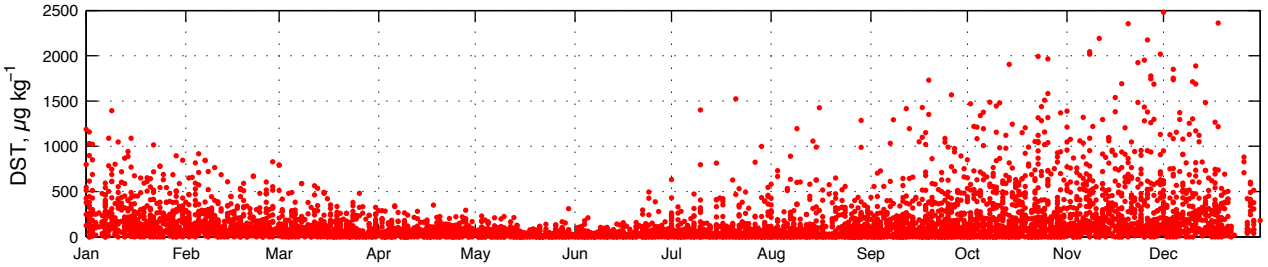


Figure 84. All measurements of DST (µg·kg^{-1}) at all locations from 1988 to 2005 presented during a year-scale. Five data points from November-December 1994 are off scale. The highest value was 4659 in December 1994..

In the Koljö Fjord area, previous studies have shown low toxin levels, despite regular recordings of DST producing algae (Lindahl & Andersson, 1996). A dramatic change of this pattern has been observed in recent years. Today mussels grown and harvested in the Koljö Fjord have similar toxin levels to mussels from other fjords in the Skagerrak region. We can only speculate about the cause of this changing pattern. One striking observation is that the increase in toxicity occurred just after a large translocation of mussel farming units from toxic cultivating areas into the Koljö Fjord area. In the Koljö fjord there is evidence for a semi local population of *Dinophysis* spp. The strong stratification and the sills "guarding" the deep water in the fjord may facilitate this situation (Axe *et al.* 2004). How long a local population exists may be related to the stochastic events with inflow of new deep water that can change the phytoplankton assemblage dramatically.

4.2 Depuration of mussels by relocation

An interesting option in the future would be relocation of mussel cultivation units to non-toxic areas for depuration. Previous attempts to depurate mussels by relocation have been made in the Skagerrack area (Haamer *et al.* 1990; Svensson 2003) In these experiments fluctuations between days were observed, but a general 50% reduction in toxicity was achieved within 7-11 days. Similar results have been obtained in laboratory experiments (Svensson & Förlin 2004). Thus, cost-effective self-depuration of mussels is possible to achieve in natural waters. However, it is of importance that the depuration takes place in waters free from or with very low concentrations of DST-producing algae.

4.3 Correlation between number of *Dinophysis* and toxicity in mussels

Forecasts of occurrence of DST in mussels are usually obtained by monitoring numbers of *Dinophysis* cells in a given area. In Sweden warnings are issued at cell densities of 100-300 cells·l^{-1} for *D. acuta* and at 900 cells·l^{-1} for *D. acuminata*. The yearly cyclic oscillation of DST in Swedish mussels can however not be correlated to numbers of *Dinophysis* cells. This lack of correlation is understandable, since an instantaneous measure is compared to an integrated value. Moreover, the Skagerrak coast algal samples are collected once a month and at different locations compared to mussel sampling areas. Variation in toxin compositions and levels in mussels can also be explained by the occurrence of different *Dinophysis* populations in the water. *D. acuminata* and *D. acuta* are normally the dominating DST producers in the area. Significantly mixed populations of *D. norvegica* and *D. acuminata* occur regularly at high concentrations without the co-occurrence of elevated toxicity in mussels, a pattern that has also been observed in other areas (Andersen *et al.* 1996). The relationships between environmental influences, growth and toxin production in *Dinophysis* are not fully understood, despite significant research efforts (*i.e.* Soudant *et al.* 1997, Blanco *et al.* 1998, Aubry *et al.* 2000, Smayda & Reynolds 2001). However, some authors emphasize the importance of stratification for high abundances (Delmas *et al.* 1992, Godhe *et al.* 2002). An interesting study by Lindahl *et al.* (2006) reported a correlation between number of *Dinophysis* cells in the Skagerrak area and toxin content per cell, *i.e.* that the toxin content per cell was significantly higher at low cell concentrations compared to high cell concentrations. The most toxic cells could be found in deeper, more saline waters. Further information related to the occurrence of *Dinophysis* spp., environmental conditions, toxicity etc along the Skagerrak coast is however beyond the scope of this report and will be published elsewhere.

4.4 Other algal toxins

The data included in this report only cover DST in blue mussels. Other toxins do occur in shellfish in the Skagerrak-Kattegat area. Paralytic shellfish toxins (PST) are produced by *e.g. Alexandrium tamarense* and *A. minutum* which occur in the area. In Denmark the diatom genus *Pseudonitschia* caused levels of domoic acid above the regulatory limit in 2005 (pers. comm. Per Andersen) and blooms may cover the whole area. Domoic acid and PST´s are very potent toxins which may cause mortality of humans and it is essential that mussels are controlled for these toxins regularly. The National Food Administration is implementing this in the shellfish safety monitoring program in Sweden (pers. comm. Ingrid Nordlander). Also other organisms may act as vectors for algal toxins to humans. In Norway the crab Cancer pagurus acted as vector for DST on the Skagerrak coast in 2002 (pers. comm. Lars Johan Naustvoll).

5 Conclusion

Bivalves are a globally important food resource. However, the feeding mode of bivalves entails special risks for consumers and can affect public health (Rehnstam-Holm & Hernroth 2005). To set up a cost-effective monitoring program an understanding of the underlying causes is necessary. These include, but are not restricted to, the ecology of the harmful plankton species, the physical oceanography of the area, and the ecology and physiology of the bivalves, *e.g.* depuration time. A monitoring program should include phytoplankton sampling and analysis, a numerical model of the hydrodynamic situation and analysis of toxins in both plankton and bivalves collected at the same locations. Thus, risks should be analyzed with respect to seasonal and geographical differences in occurrence of algal toxins, hydrodynamic situations and the species of bivalve being cultivated, etc. With such an approach, the design of control programs will differ between areas with priority given to public health in areas where wild mussels are harvested by the public and areas where mussels are farmed for trade marketing. Much further research and collaboration regarding monitoring is however needed before we can reach this objective. Hopefully both national and international new initiatives will lead to its success.

6 References

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