Prepared for:

RIKZ

A first validation of BLOOM for species groups

Report

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B. van Wesenbeeck

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Client:	RIKZ
Title:	A first validation of BLOOM for species groups

Abstract:

The central question in this report was the validation of the BLOOM-module concerning phytoplankton species composition and biomass. Model runs were executed for the years 1991 till 2003. 2D-simulations were done from 1991 till 1995 and 3D-simulations were executed for the remaining years (1996-2003). Outcomes of these simulations were compared with monitoring data from the DONAR database, using a cost function. Results show that in general chlorophyll concentrations are accurately predicted by the model. Concerning species group composition, diatoms and *Phaeocystis* are well predicted, but dinoflagellates and flagellates biomasses deviate considerably from the monitoring data, especially for the 2D-simulations. Surprisingly, 3D-modeling fails to obtain precise estimates at stations that show stratification during summer. This asks for evaluation of the BLOOM-module in stratified areas and possibly adaptations to the model to make it better applicable to stratified zones. In conclusion, in general the BLOOM-module seems applicable for use in both 2D- and 3D-simulations. Forecasting of diatom and *Phaeocystis* blooms by means of BLOOM is mostly good till very good. Although 3D-simulations seem to gain better results, 2D-simulations still are a useful and sufficient precise tool, depending on the exact use of the model. Some improvements of the BLOOM module to predict algal biomass, especially under stratified conditions, are suggested. It is recommended to examine the possibilities for developing a standard routine for comparing model data and measurement data.

References:

Ver	Author	Date	Remarks	Review	Approved by
	B. van Wesenbeeck			T. Troost	T. Schilperoort

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Contents

1 Introduction

1.1 Background and problem definition

Phytoplankton is an important indicator for water quality both in fresh and in salt water, as phytoplankton affects many factors related to the ecological quality of the water, such as turbidity, oxygen depletion and productivity of the system. Therefore, in the Water Framework Directive (WFD) that is currently being implemented by the EU member states, phytoplankton is one of the biological quality elements used to asses ecological status of a water body. In the WFD, both the composition and abundance of phytoplankton are taken into account. For the North Sea, the used proxies are the 90-percentiles of chlorophyll-a over the main blooming period (March-September), and the frequency of *Phaeocystis* blooms ($>10^6$ cells l^{-1}), one of the most conspicuous marine nuisance algae (van der Molen 2004).

Phaeocystis is not always used as main indicator for eutrophication. For example, some dinoflagellate species are also used as an indicator by the OSPAR Convention (Convention for the Protection of the Marine Environment of the North-East Atlantic), as blooms of these species are also frequently observed in the North Sea. Although phytoplankton blooms are enhanced by eutrophication (van der Molen 2004), the correlation between blooms of dinoflagellate species and nutrient concentrations is not that evident. For P*haeocystis* this relationship is evident. Based on phytoplankton measurements the ecological status of the Dutch coastal waters of the North Sea can be described as "moderate to good".

The occurrence of phytoplankton species in relation to environmental conditions is not always clear. This is partly due to the effects of large-scale processes, such as large-scale hydrodynamics, on phytoplankton dynamics (Cloern 1996, Yin 1999). On top of that, relationships between phytoplankton dynamics and environmental processes are obscured by the interaction between large- and small-scale processes (Breton et al. 2006). For example, in the northwest European shelf seas, phytoplankton dynamics are influenced by the North Atlantic Oscillation (Hurrell 1995). Also the effects of changes in phytoplankton dynamics on the rest of the community or ecosystem are not well understood. That such effects may exist is shown by recently observed changes in the Marsdiep (Wadden Sea). There, a change in the phytoplankton community (specifically a shift in species occurrence) has been observed, which is potentially caused by a change in nutrient availability. This change seems to set off a feedback mechanism (Phillipart et al. 2007), which also affects higher trophic levels. This stresses the fact that changes in phytoplankton dynamics might in turn affect the whole community of an ecosystem.

Today we are just beginning to unravel the complex relationships between occurrence and abundance of phytoplankton species and abiotic conditions. We are hardly able to make accurate predictions of when and where algal blooms will occur, especially in marine systems. Besides the ongoing long-term sampling programs, there is an urgent need for accurate models to obtain a better insight in phytoplankton blooms and to predict their occurrences. In addition, models may also be helpful in predicting the effects of changes in

phytoplankton dynamics on higher trophic levels and in testing the effectiveness of various management measures.

Although it is not expected that all uncertainties in the relation between eutrophication and phytoplankton biomass, species composition and community structure can be decreased by modeling, it is considered necessary for our problem understanding to be able to make more accurate forecasts with respect to phytoplankton biomass, species composition and community structure, especially in the light of forecasting the effectiveness of measures by means of numerical modeling. Validation of the simulated species composition was also one of the recommendations by the international review panel of the GEM model during the audit in 2006 (WL | Delft Hydraulics, 2006).

1.2 The project

WL | Delft Hydraulics was asked by the National Institute for Coastal and Marine Management (RIKZ) in Middelburg to perform a validation of the BLOOM module as part of the GEM Southern North Sea ("ZUNO") model using data from the MWTL programme database for the period 1990 – 2005 (request for proposal reference nr. RKZ-1903, dated 26th June 2007). The project was said to consist of three parts:
1. A trend analysis of the monitoring data, to determine the focus of the validation study
2. A single or several simulations with the BLOOM model
3. Validation of model results.

Finally, recommendations for optimization of phytoplankton modeling with the BLOOM module will be given.

The study was performed at WL | Delft Hydraulics by S. Tatman (project leader), B.K. van Wesenbeeck, X. Desmit and F.J. Los. Theo Prins and Hanneke Baretta-Bekker supported the study on behalf of RIKZ. T. A. Troost did the internal review.

1.3 Objectives

The aim of this project is to validate the BLOOM-module in the GEM ZUNO (Zuidelijke Noordzee) model with respect to phytoplankton biomass and species composition, using the phytoplankton data from the DONAR database from 1990-till 2005.

Using the definition by Refsgaard and Henriksen (2004), we define 'validation' as 'evaluating the accuracy of a model for its application within the field for which the model is developed'.

1.4 Outline of this report

In chapter 2 the Generic Ecological Model (GEM) for coastal and estuarine waters and its algal module, called BLOOM, is described. Chapter 3 deals with the model set-up of this

specific study and describes the post processing of the results. These results are presented in chapter 4 and discussed in chapter 5. Finally, conclusions are presented in chapter 6.

2 The GEM model

2.1 About GEM and BLOOM

The model used for this study is the Generic Ecological Model (GEM) for estuarine and coastal waters. GEM was developed by several Dutch marine research institutes in the period from 1995 till now. The first model documentation was written in 1997 (Smits et al., 1997). An update of the model documentation took place in 2003 (Blauw et al., 2003). The model has been calibrated for the Dutch coastal zone in 1999 (Blauw et al., 1999) and was applied and validated, with (mostly) the same parameter settings, for the ecosystems listed below:

- Dutch coastal waters (Bokhorst and Los, 1997; Los and Bokhorst, 1997; Blauw et al., 1998; Blauw et al., 1999; Blauw, 1999; Blauw and Los, 2000; Wijsman, 2002);
- the Ems Estuary (Blauw and Smits, 2002; Smits et al., 2003);
- lake Veerse Meer (Nolte and Bijvelds, 2000; Smits et al., 1999, Nolte and Jansen, 1999);
- Wadden Sea and Westerschelde (Blauw and Boderie, 2001; Boon et al., 2003);
- the southern North Sea (MARE, 2002).

In this study we use the most recent application of GEM for the southern North Sea. This model application covers only the Dutch coastal waters. Figure 3.1 shows a schematic representation of the processes included in GEM. In this study a simplified version has been used, without microphytobenthos, grazers and phosphate adsorption to suspended solids.

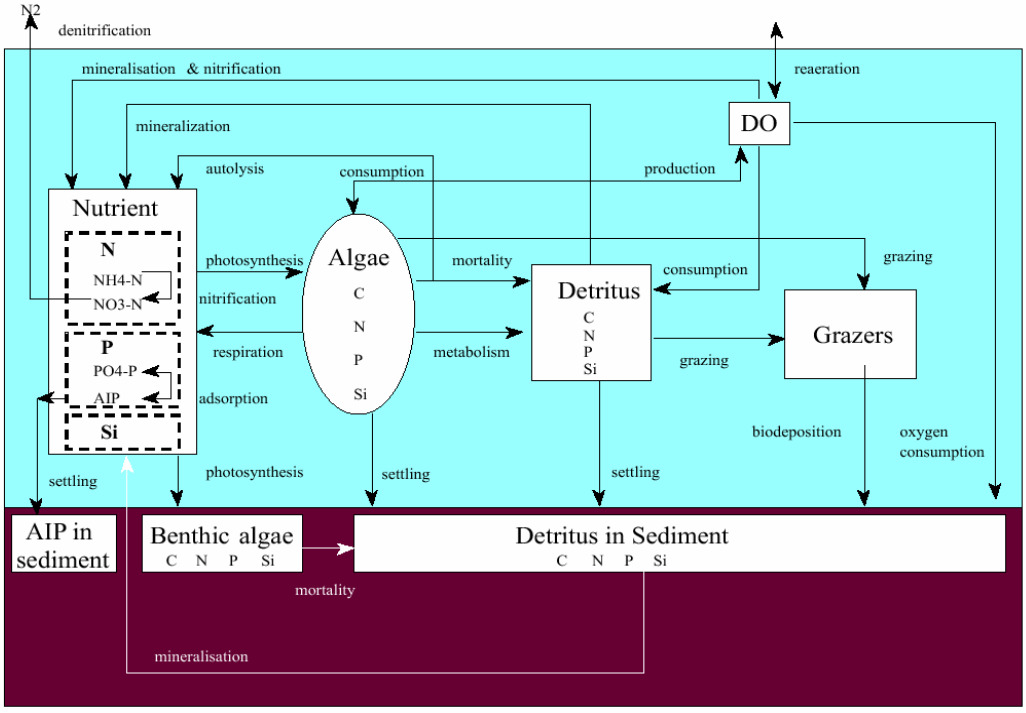

Figure 1 Schematic overview of the substances and processes incorporated in GEM.

BLOOM is a module within GEM to model the competition between species and the adaptation by species to limiting factors such as nutrients and light (Los *et al*. 1984; Los and Brinkman, 1988; Los and Bokhorst, 1997; Los and Wijsman, 2007). In this module, the maximum net growth is optimized, which is done by selecting a combination of species groups that uses the limiting factor (nutrient or light) most efficiently and reaches the highest net growth rate. Optimalization is done by linear programming. The BLOOM-module has been validated at six stations (Los & Wijsman 2007), for chlorophyll-a production. However, the species composition output has not been validated yet. For more detailed descriptions of GEM and BLOOM we refer to the GEM user guide (WL | Delft Hydraulics, 2002).

3 Material and methods

3.1 General approach

The main objective of this study is to validate the BLOOM phytoplankton output for the Southern North Sea at the level of species groups. For this validation phytoplankton data from the DONAR dataset of Rijkswaterstaat is used. Data is aggregated into three groups of species (diatoms, dinoflagellates and flagellates) and one specific species (*Phaeocystis*). The output of BLOOM consists of values for the same groups and species as the database data. Model simulations were executed for the Southern North Sea from 1991 till 2003, for each year separately, using the last result of the previous year as start conditions. Simulations were executed in 2D for the years 1991-1995. For these years only 2D hydrodynamics are available yet. For the years 1996 till 2003 3D hydrodynamics are available and therefore it was chosen to run these simulations in 3D. For all these simulations model output for the species groups is validated using cost functions. Results are presented in plots for four stations that were included in the sampling program as well as marked as observation points in our simulations. One station close to the shore is taken, Noordwijk 10, and a more offshore station, Noordwijk 70. Data is also presented for two stations that are expected to gain somewhat different results, Terschelling 135 (Oyster Grounds), which is stratified, and Terschelling 235 (Dogger Bank). For all stations the simulated and measured data are presented for the average biomass for each species in each year. For the stations on the Noordwijk transect the simulated and measured chlorophyll concentrations are presented as well. This enables a comparison between the accuracy of the output for separate species groups and that for total chlorophyll concentrations, since we know that BLOOM predicts chlorophyll concentrations accurately as it has been validated for chlorophyll before (Los & Wijsman 2007; Los et al., submitted).

3.2 Validation data

The biotic data from the DONAR-database of Rijkswaterstaat from the years 1991 till 2003 is used to validate the model results. The sampling frequency of this data varies between two weeks and one month. Sampling is carried out at fixed stations. Phytoplankton is determined at the species or genus level and the concentration of species is counted. From this value the final biomass is calculated in milligram carbon per cubic meter (mgC/m^3). Transferring number of cells to biomass is done by using the widely applied formula proposed by Menden & Lessard (2000).

3.3 Set-up of the model applications in this study

3.3.1 Set up 2 D model (1991 – 1995)

Hydrodynamics
All simulations are done with the ZUNO-GROF grid for the southern North Sea. Hydrodynamic simulations are executed in 3D-mode and vertically averaged. The

hydrodynamic forcings are based on a representative 14 day tidal cycle and this same cycle is used repeatedly within a year. Thus, transport for the 2D-simulations does not vary between different years. This set-up is the same as for Flyland (Mare, 2002).

Initial conditions
The initial conditions for the 2D-simulations are calculated by running the model for the year 1990. These conditions are used as an input for the 1991 model and thereafter the initial conditions of each year are taken from the last time-step of the previous year.

Boundary conditions
The boundary conditions for the simulations (i.e. the concentrations of all substances at the boundaries in the Channel and in the northern North Sea) are the same in all 2D-simulations. They have been adopted from Flyland (Mare 2002).

Rivers and other nutrient sources
Dutch river loads for the 2D model have been obtained by Blauw et al. (1999) during the set-up of the GEM model for the Dutch coastal zone. Loads for German and UK rivers are based on old results of the Mans project (Los et al. 1994) and were also used for the CSM model developed for Ospar 1996. These same loads were later used for Flyland.

Other Forcings
Forced parameters include: suspended solids concentrations (SPM) (in order to calculate the background transparency), solar irradiance, wind speed (for re-aeration) and water temperature. All forcings are adapted according to the simulated year. SPM is based on an average which was calculated using aerial photographs. This average is corrected for each separate year on a weekly basis by using wind velocities for the specific year. Temperature is taken from station Noordwijk 10. Time series of irradiance and wind velocity are obtained from the daily observations by KNMI at station “de Kooy”.

3.3.2 Set up 3D model (1996 – 2003)

All simulations are done with the ZUNO-GROF grid for the southern North Sea. For the 3D GEM simulations the grid has ten sigma layers and historic (hourly) forcing. The used hydrodynamics were developed during the Maasvlakte project (de Goede & van Maren 2005). These hydrodynamic simulations include the actual forcing of rivers discharges, wind and atmospheric pressure. Hence, GEM runs with actual hourly hydrodynamic results for the entire simulation period (1996 – 2003).

Initial conditions
The initial conditions for the 3D-simulations of 1996 are determined from a 3D-simulation that was executed in the OSPAR project (Blaas et al 2007). To compute the initial conditions in 1996, a run is done with the 1996 setup and initial conditions from 1995 as calculated in the OSPAR project. From there on, the initial conditions of each year are taken from the last timestep of the previous year.

Boundary conditions
The boundary conditions for the simulations (i.e. the concentrations of all substances at the boundaries in the Channel and the northern North Sea) are taken from the Afwentelings project (Blauw et al., 2006). For the Channel, these boundaries are the same as for the 2D

simulation, while for the Atlantic boundary, updated values are used based on recent research. Concentrations of the GEM substances at the boundary are divided equally over the ten layers. Both boundary conditions consist of timeseries over a single year, showing differences in seasons.

Rivers and other nutrient sources
River loads are taken form Afwenteling (Blauw et al, 2006). In 3D we assume that at the discharge points the vertical mixing is such that the concentrations are rapidly (almost instantaneously) homogenised in the water column. This assumption is verified in the model by activating a tracer that moves through the different layers. Atmospheric loads are identical to the ones in Afwenteling (and Ospar 2007). At each time step, a certain amount of nitrate and ammonia is deposited in each surface segment of the water column.

Discharge observations are generally available on a daily basis. Observations on concentrations of substances in waters are generally available once or twice per month, depending on the season. The discharges and concentrations were converted into 10 day averaged loads by RIKZ as part of the Afwentelings project (Blauw, 2006), which have been used again in the present study.

Forcings
As for the 2D model, the 3D model requires forcing information on: suspended solid concentrations (in order to calculate transparency), solar irradiance, wind speed (for re-aeration) and water temperature. All forcings are adapted according to the simulated year. SPM forcing of the 3D model is determined in the same way as for the 2D model. It is based on an average which was calculated using aerial photographs. This average is corrected for each separate year by using wind velocities for the specific year. Because in 3D temperature varies not only in horizontal but also in vertical direction, in the 3D model computed temperature values are used. These are determined by the hydrodynamic model (Delft3D-Flow). However, simulated temperature were somewhat too high (Blaas et al. 2007) and therefore slightly adjusted: from all temperatures 2.5 °C was subtracted. The forcings irradiance and wind velocity are timeseries computed from the daily observations by KNMI at station “de Kooy” (same procedure as in 2D).

Notice that the 2D- and 3D-simulations do not only differ with respect to vertical mixing and model years, but also with respect to its forcing (spring tide/low tide forcing for 2D-simulations and historic and actual forcing for the 3D-simulations) and with respect to the used nutrient loads.

3.4 Interpretation of results

The comparison between the DONAR data and the model output is done by calculating cost functions and making plots. Plots were made for four locations, for the four species groups and for all the years separately. They contain a line for the model output of a specific year, and dots for the samples of the same year. In addition, the mean, median and standard deviation for all remaining samples are shown for each month. Cost functions are calculated to allow for a more objective way to compare the accuracy of the model. The cost function gives a non-dimensional number which is the sum of absolute deviations of the model values from the observations, normalized by the standard deviations for the observations

over a specific spatial and temporal range (Radach & Moll 2006). Thus it is a standardized, relative mean error. Its formula is defined as follows:

$$C_x = \frac{\sum \left| M_{x,t} - D_{x,t} \right| / n}{sd_x} * ((1-c) + c(1-r_x)$$

where C_x is the normalised annual deviation per station, $M_{x,t}$ is mean value of the model results per station per month, $D_{x,t}$ is mean value of the in situ data per station per month, s_{dx} is standard deviation of the annual mean based on the monthly means of the in situ data (df=11), n is 12 months, c is 0.5 and r_x is the correlation over time between $M_{x,t}$ and $D_{x,t}$. The resulting values of the cost function should be interpreted as noted in Table 1.

Table 1 Interpretation of cost function values (cf) according to Radach and Moll (2006).

Rating	Condition	
Very good	0 < cf ≤1	Standard deviations
Good	1 < cf ≤2	Standard deviations
Reasonable	2 < cf ≤3	Standard deviations
Poor	3 < cf ≤	Standard deviations

4 Validation results

In this chapter the model results are compared with field observations at monitoring stations. Figures for separate stations can be found in the Appendix. These stations include a station near the shore and a station more offshore (Figure A.1: Noordwijk 10 and 70), and two other stations that are frequently sampled (Figure A.2: Terschelling 135 and 235, also known as 'de Oestergronden' and 'de Doggersbank').

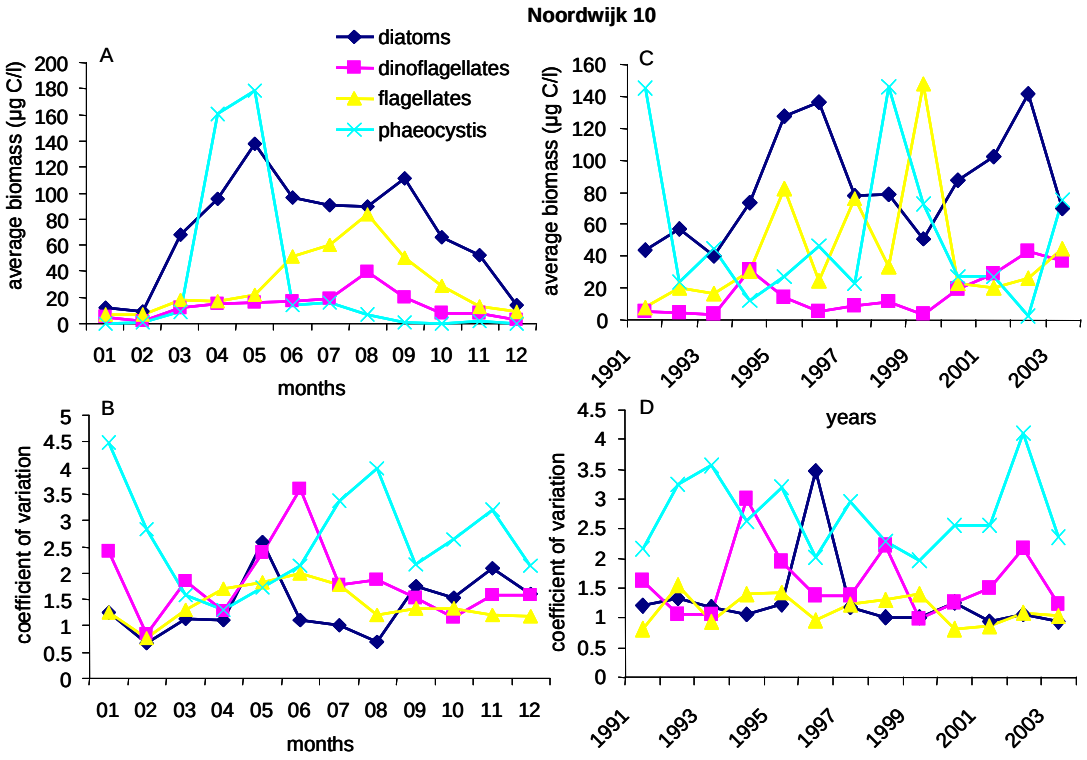

Figure 2 Average biomass and coefficients of variation for phytoplankton species at the station Noordwijk 10 for all years, (A+B) over months and (C+D) over years.

4.1 Trends in monitoring data

Figure 2 and 3 shows trends for phytoplankton species groups over months and over years for the stations Noordwijk 10 and Noordwijk 70. The average biomass and the coefficient of variation are depicted for each species group. The coefficient of variation is the standard deviation divided by the mean and, thus, offers an insight in the amount of variation independent of the mean. It is clear that each group exhibits a strong seasonal trend within a year (Figure 2A and 3A). Over the years 1991 till 2003 no clear trend is detectable for any of the groups, besides a possible increase in diatom biomass at the Noordwijk 70 station. For *Phaeocystis* and flagellates considerable variation between years is found for both stations (2D and 3D).

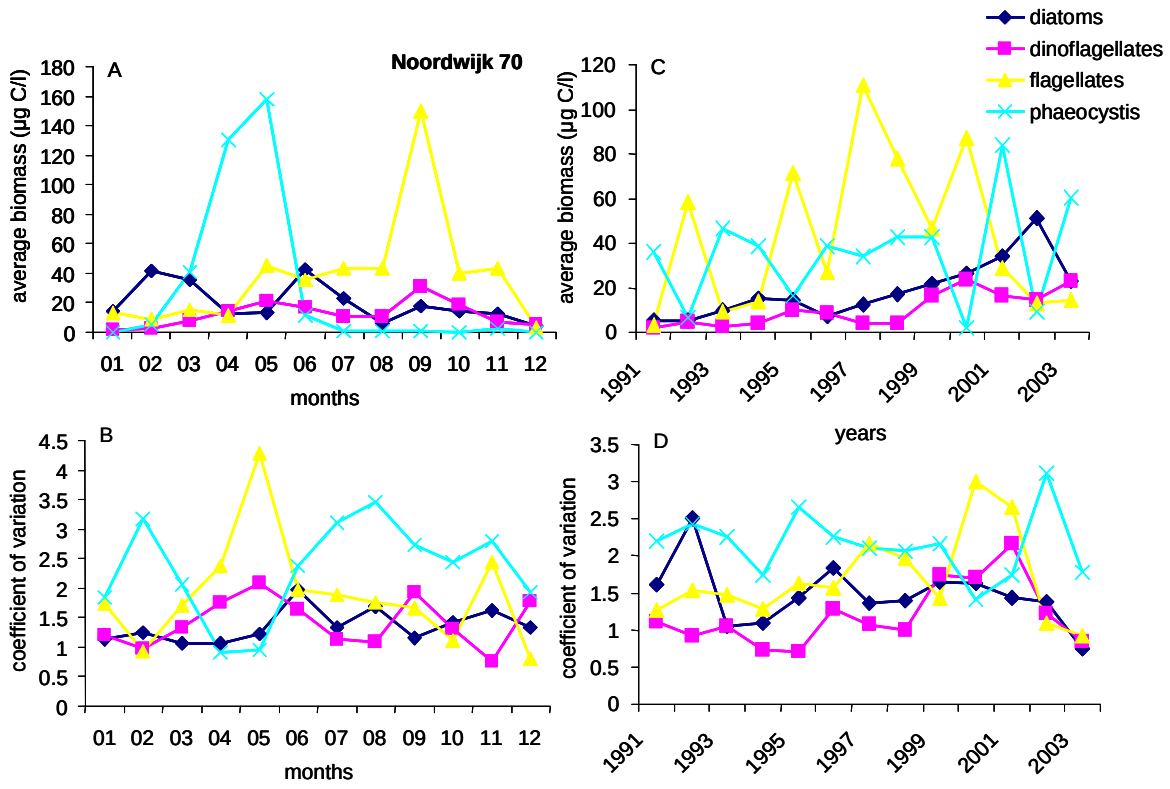

Figure 3 Average biomass and coefficients of variation for phytoplankton species at the station Noordwijk 70 for all years, (A+B) over months and (C+D) over years.

Data for the stratified stations Terschelling 100, 135 and 175 is presented in Figure 4. It can be seen that once stratification takes place usually the highest biomass is reached in the middle layer. This confirms expectations that in the middle layer the combination of light and nutrient availability generates most optimal conditions for algal growth, compared to the upper layer, where nutrients are the limiting factor and the bottom layer where light availability is low.

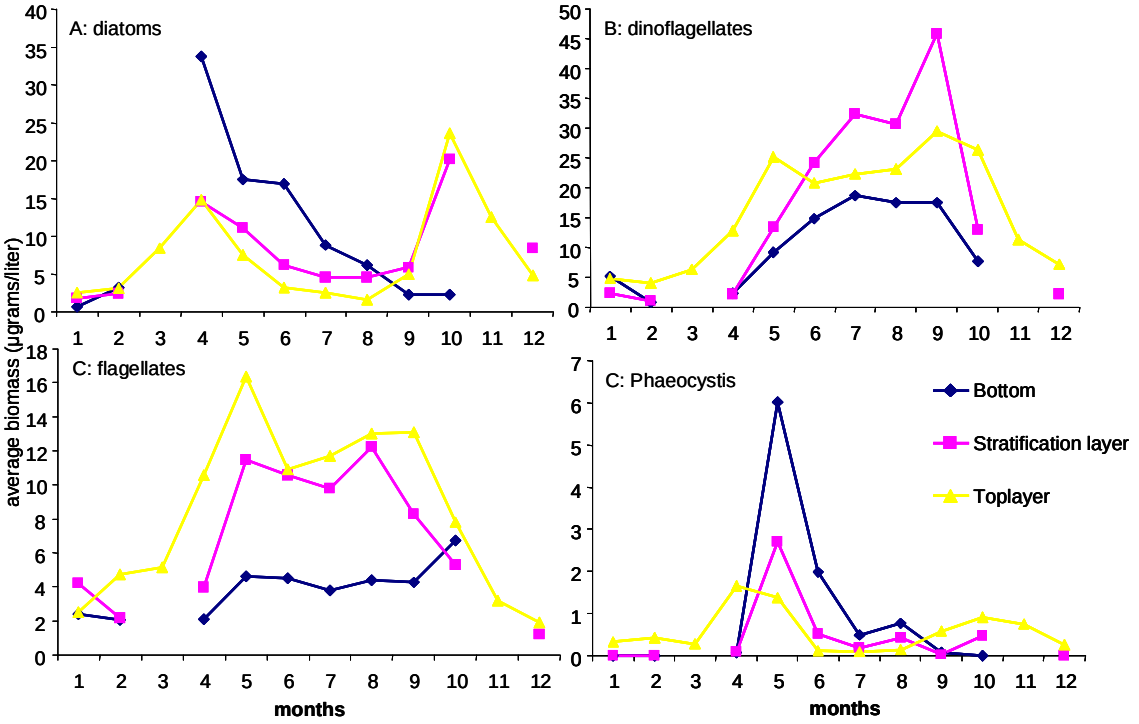

Figure 4 Average biomass of phytoplankton species in different layers for two of the stratified stations (Terschelling 100 and 135) for all years.

4.2 General trends over the years

From visual comparison of the model results and the measured data (Figures in Appendix) it seems that *Phaeocystis* is being predicted the best of all species groups. However, the cost functions prove exactly the opposite (Figure 5). The average cost value for each species group indicates that diatoms are best predicted and *Phaeocystis* worst. However, the standard deviation for *Phaeocystis* is rather large. More detailed exploration of the data reveals that cost function values for the stratified stations on the Terschelling transect are relatively high (TS 100, 135 and 175, Figure 6). For the other stations, particularly for the Noordwijk transect, cost values are lower, indicating that model outcomes do not deviate much from the monitoring data. Looking into more detail reveals that especially *Phaeocystis* is very badly predicted for the three Terschelling stations (Figure 7). Values of the cost function for *Phaeocystis* at other stations are among the lowest. After omitting the three stratified stations from the analysis both *Phaeocystis* and diatoms are the species that have lowest cost values (Figure 8).

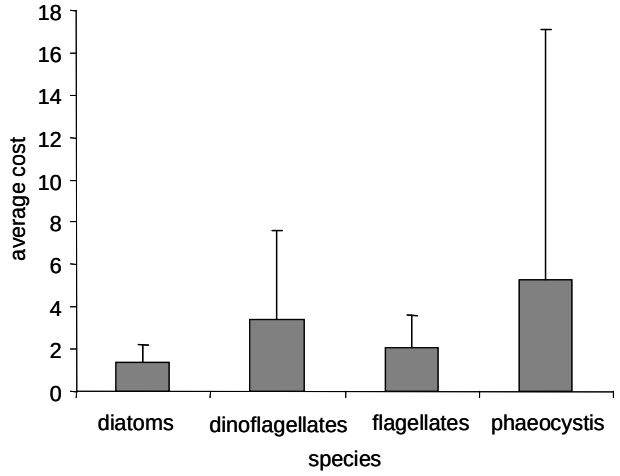

Figure 5 Average cost function values for the different species for all years. Bars indicate standard deviations.

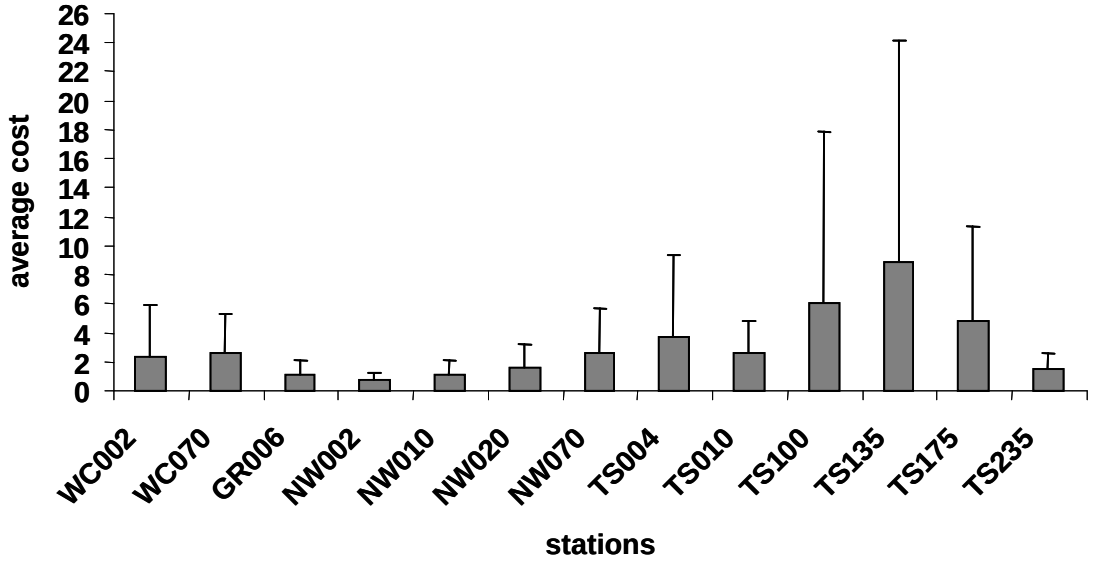

Figure 6 Average cost function values for the different stations. Bars indicate standard deviations.

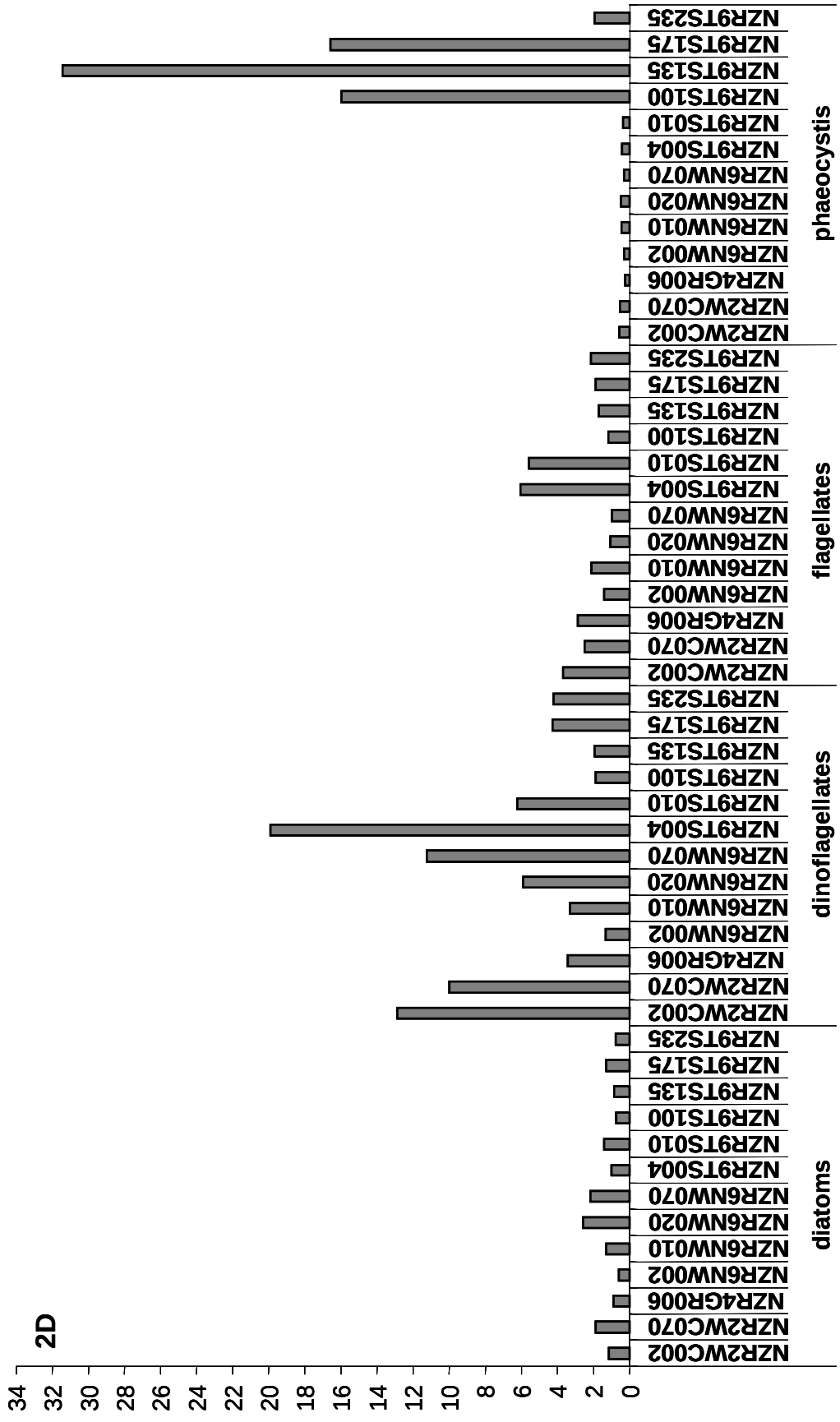

Figure 7 Average cost function values of the 2D simulations (1991-1995) for each species for all stations.

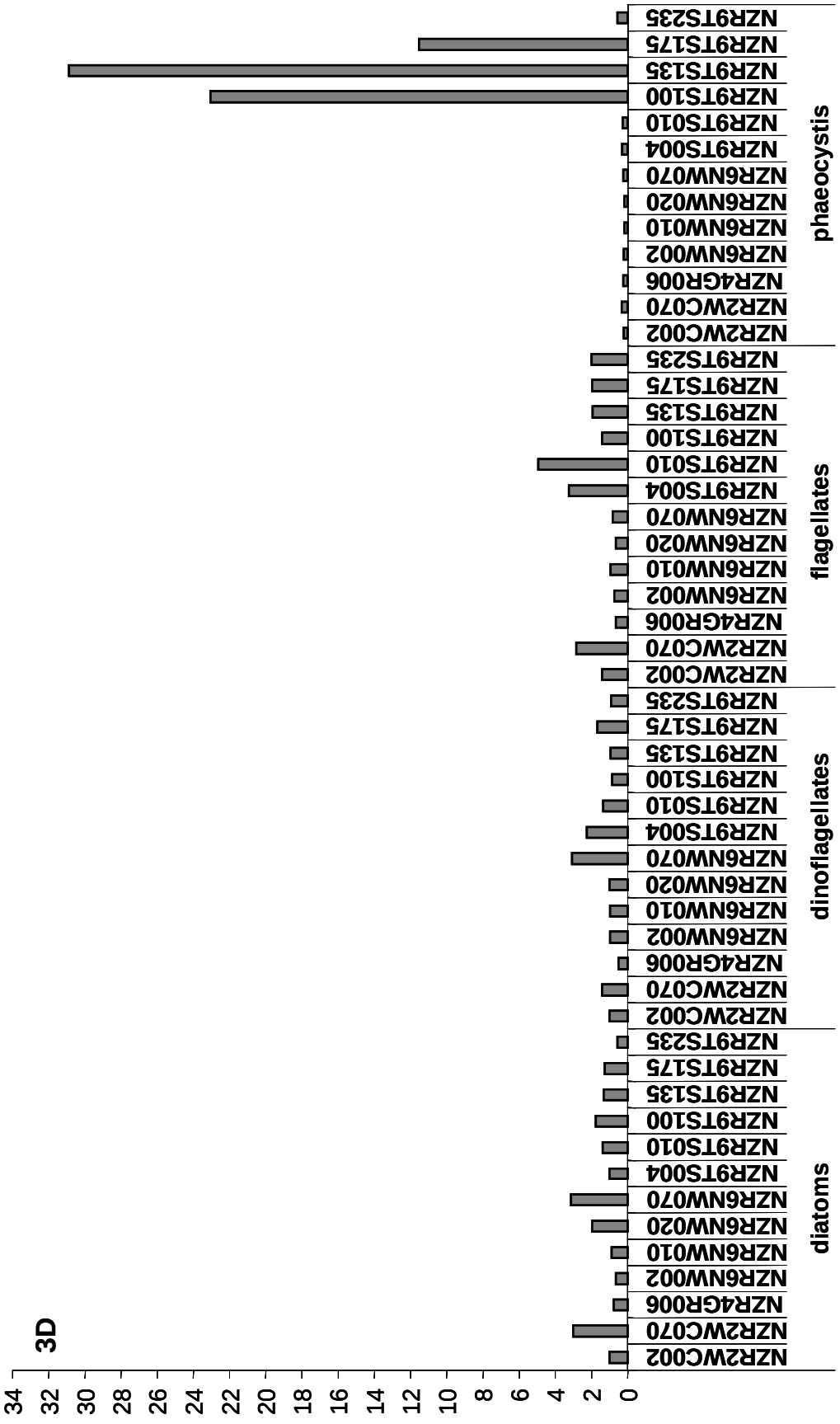

Figure 8 Average cost function values of the 3D simulations (1996-2003) for each species for all stations.

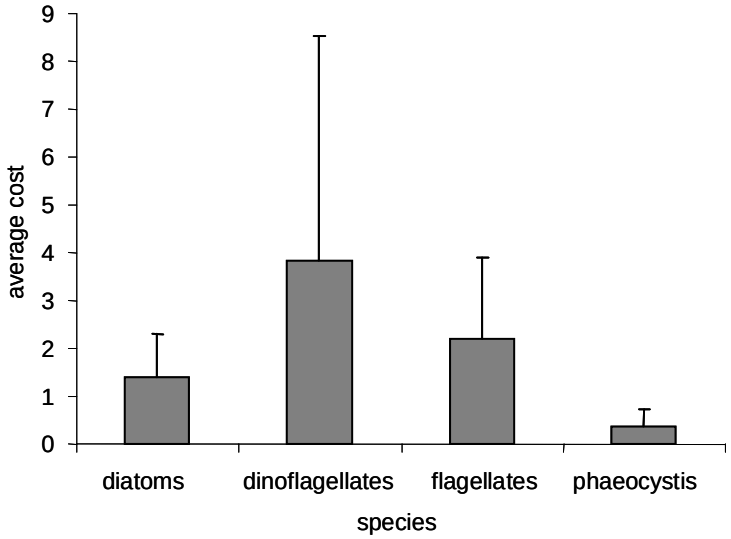

Figure 8 Species cost functions after eliminating the stratified stations Terschelling 100, 135 and 175. Bars indicate standard deviations.

4.3 Comparing 2D (1991-1995) and 3D results (1996-2003)

It seems that predictions from the 3D simulations are better than those from the 2D simulations. This is confirmed by the analysis of the cost functions (Figure 9). Values resulting from the cost function are considerably lower for 3D simulations, pointing at the fact that 3D-simulations better resemble the measurement data for an average year. The first year with the 3D-simulation (1996) shows the worst results, the highest values for the cost function, and the largest standard deviation. Probably the start conditions for this year, which were taken from the OSPAR project (Blaas et al. 2007) are not suitable and it takes over a year for the model to reach an equilibrium. The other years modeled in 3D seem accurate. Model trends in flagellates and dinoflagellates are not mirrored in the monitoring data, especially for the Noordwijk stations (Appendix, Figure A.1). The 3D-simulations do a considerably better job in predicting occurrence of these species groups.

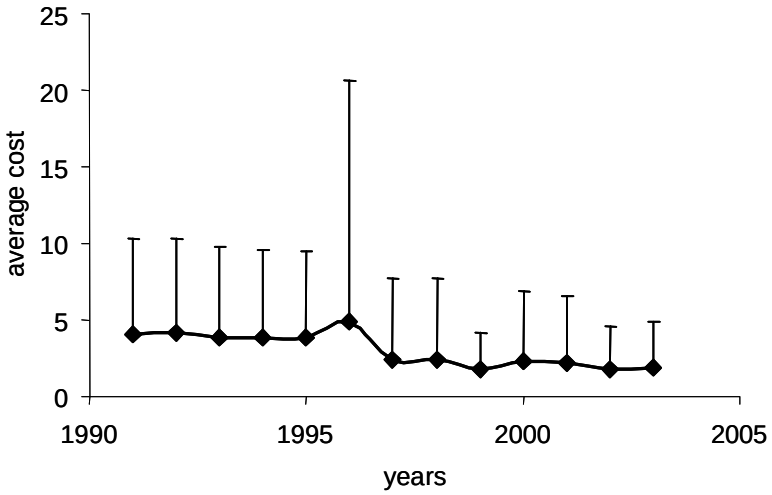

Figure 9 Average cost function values per year. Bars indicate standard deviations.

Average values of the cost function over the years were also plotted after omitting the stratified stations (Figure 10). This gains much better results, especially for the 3D simulations and the year 1996. It is striking that standard deviations are considerably higher in the 2D results compared to the 3D results.

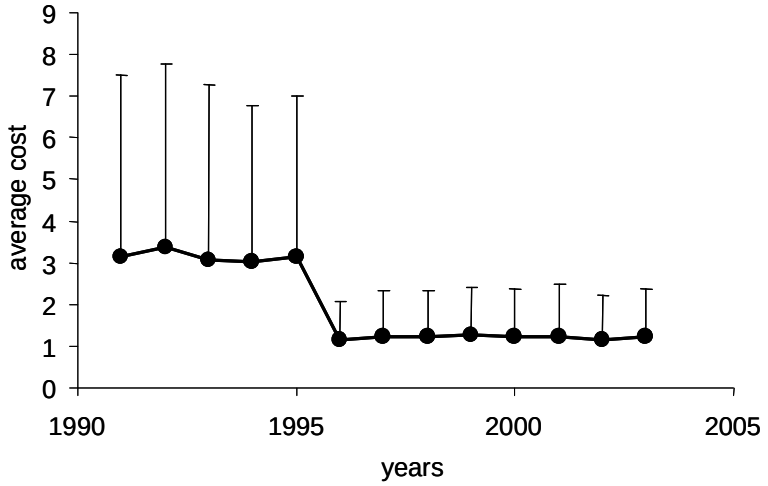

Figure 10 Average cost function values per year after eliminating the stratified stations Terschelling 100, 135 and 175. Bars indicate standard deviations.

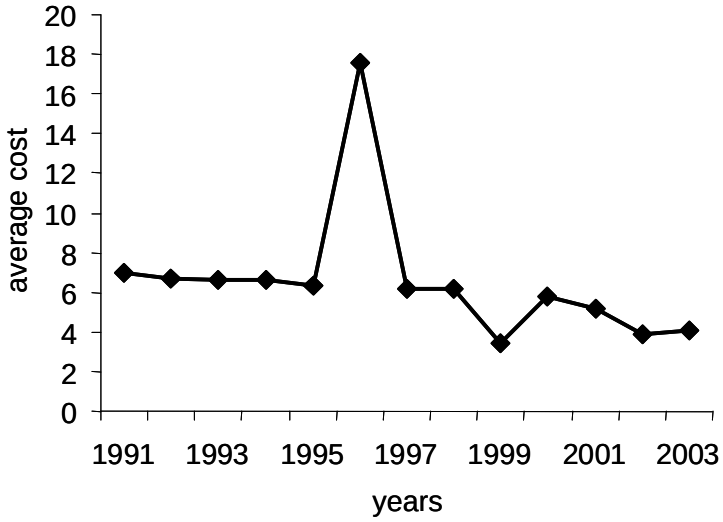

Figure 11 Average cost function values per year for the three stratified stations Terschelling 100, 135 and 175.

4.4 Comparing coastal and open sea results

As can be seen from comparing graphs for the Noordwijk 10 and the Noordwijk 70 station from 1996 till 2003 (Appendix, Figure A.1.) dinoflagellates are found more at the open sea whereas flagellates typically are more abundant in the coastal zones. Diatoms seem slightly more abundant in coastal zones than in the open sea as well. The model seems to predict species composition equally well for near shore and offshore stations in the coastal zone (Figure 6+7).

4.5 Comparing species and chlorophyll trends

Some of the plots in the appendix show a higher simulated phytoplankton biomass than was found in the actual measurements. To check whether this deviation is also present in the *total* phytoplankton biomass, we compared modeled and measured chlorophyll concentrations for the Noordwijk stations (Figure A.3). The agreement between measured and observed chlorophyll concentrations is generally satisfactory, illustrating that the deviation between model and measurements should be sought at the level of the species groups. Several phenomena can occur, explaining differences between biomasses in the model output and the biomasses that are calculated from cell counts

In the sampling procedure cells are counted and then, the number of cells is translated into an estimate of biomass for each species group. This can be done using different transformation formulas, of which the Menden-formula is the most broadly applied (Menden & Lessard 2000). To compare measured chlorophyll with the total biomass based on counts of cells measured chlorophyll is converted to grams of algal carbon. For this calculation different conversion factors are available. Ideally, this conversion factor should be adjusted for each species group and for each season. The BLOOM module uses different conversion factors for each species in different seasons. We plotted the minimum and maximum conversion factor as found in the BLOOM module and in literature. We compared the average biomass calculated from chlorophyll with the range between these factors (Figure 12). The monthly average total biomass for the monitoring data derived from the cell counts overlaps for most parts with the biomass that was calculated from chlorophyll with the low conversion factor. This would imply that algae are severely light limited for the whole year, which is, for example, not likely to be the case during their spring bloom.

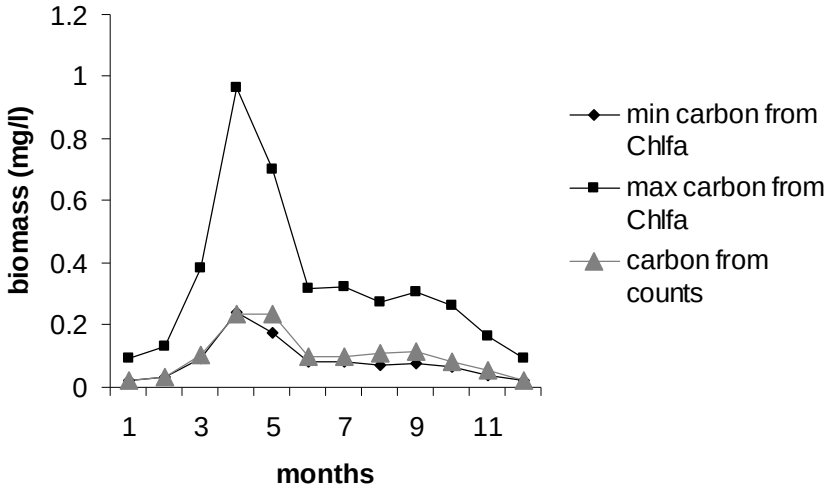

Figure 12 Biomass of the total counted phytoplankton in mg carbon per liter (gray line). Black lines represent measured chlorophyll concentrations with conversion factors of chlorophyll to carbon of 20 (lower line) and 80 (upper line).

5 Discussion

Eutrophication is an important cause for blooms of harmful algae both in freshwater systems and coastal waters (van der Molen 2004). Most phytoplankton species react strongly to changes in available nutrients. High concentrations of nutrients can cause normal peaks in algal growth to become amplified and usually harmless algae to become a plague and cause damage to tourism, mussel industry and farmers. To maintain an acceptable water quality it would be advantageous to have a better insight in the occurrence of these blooms and into the factors that trigger them. Modeling can be a useful tool to predict the occurrence of harmful algal blooms. The need for better models to predict phytoplankton occurrence at the level of species groups or species forms the basis of this study. The BLOOM module, which is a part of the GEM model, has never been validated quantitatively on the level of species groups for a marine model application. Therefore, the National Institute for Coastal and Marine Management (RIKZ) in Middelburg asked WL | Delft Hydraulics to validate the BLOOM module as part of the GEM Southern North Sea ("ZUNO") model using data from the MWTL programme database for the period 1990 – 2005.

Several conclusions could be made based on a comparison of model and monitoring data. These conclusions are divided in general trends, regional trends, comparison of 2D- and 3D modeling and a summary of problems with data interpretation. In general it can be concluded that measured diatom and *Phaeocystis* biomasses are represented best in the model results, especially after omitting stratified stations. Concerning regional trends the trend that flagellates are more abundant in coastal zones compared to areas that are further offshore is depicted reasonably. Currently, it seems that models are not reliable in predicting the springs bloom in stratified areas, nor 2D nor 3D. However, overall 3D-simulations gain better results.

General trends in abundance of species groups were analyzed for different years and different stations. Both in the monitoring data and in the model results the seasonal trend within a year seems rather dominant compared to trends over several years. Both in the model and in the monitoring data the blooming peak is short and early for *Phaeocystis* and stretched over a longer period for diatoms. Diatoms seem to occur throughout the model in all years and for all stations. The model estimation of their abundances is rather good, although the large peaks during the bloom predicted by the model are not reflected in the data. Often the decline of silicate during the bloom period (not shown here) as simulated in the model corresponds well with the decline in silica as measured (i.e. Los et al., 2008). This suggests that the actual size of the bloom might be somewhat larger than expected based on the cell counts. Model and monitoring results correspond well for *Phaeocystis*, especially for the 2D-simulations and the 3D-simulations excluding the stratified stations. This may be explained by the fact that *Phaeocystis* is the only species that has been modeled separately, while other phytoplankton have been modeled as species groups consisting of different species. These different species have a different ecology and, thus, different blooming periods. Lumping these species in one group obviously messes up the results and results in dampening of the effects of separate species, i.e. a higher variation around a monthly average but lower variation between averages of different months.

Next to general trends there are several stations that show specific results that are not in line with other results for other stations. Such regional trends can be distinguished for stations that are close to the coast and stations that are more offshore. For instance for dinoflagellates, 2D-simulations show little regional difference: dinoflagellates are abundant everywhere during summer. In the 3D simulations dinoflagellates almost disappear from Noordwijk 10, but not from Noordwijk 70. However, monitoring data do not really support this for the stations Noordwijk 10 and 70. Dinoflagellates were hardly measured in any of the stations. Flagellates seem to be more abundant in the coastal zone.

More examples of regional deviations are found at the Terschelling stations, probably due to stratification during the summer occurring in three stations on this transect. For example, model results of *Phaeocystis* are not very good for the station Terschelling 100, 135 and 175 (Oysterground region). Data do not show occurrence of *Phaeocystis* at all at these stations. However, the model keeps predicting *Phaeocystis* presence. At the three Terschelling stations, stratification frequently occurs in summer, which may explain the deviation between the measurements and the results of the 2D-simulation for this station. Nevertheless, 3D-simulation results for *Phaeocystis* at this station are also not very correct As at other stations predictions for *Phaeocystis* are relatively good, a possible factor that interferes with predicting *Phaeocystis* blooms accurately could be the mixing depth and thus the onset of stratification at the station Terschelling 135. At this station depths are considerably higher than at other stations. Depth influences the average under water light intensity, which is an important determinant for all phytoplankton species but for *Phaeocystis* in particular. Since the background turbidity is more or less similar, but the depth is much higher at the Oyster Grounds, the average light intensity at the Oysterground region is lower than at the Dogger Bank or at Noordwijk 70. So before the onset of the stratification, the model does not produce any phytoplankton at all. At the beginning of the summer half year in April, mixing is gradually reduced. At a certain combination of vertical mixing, turbidity, light intensity and temperature, the threshold for growth is exceeded. In the model this happens abruptly for three different species groups (diatoms, flagellates and *Phaeocystis*) almost at the same time. As a result all three groups start growing (almost) at the same moment. Since the availability of light increases more rapidly than the actual growth rate of the species, the model starts producing all three groups and all three of them are growth limited. This is a typical example of opportunistic, pioneer behavior. This behavior continues until one or more resources are exhausted. Hence, the model includes *Phaeocystis* in the spring bloom, because it selects all the species that could possibly grow at the rapidly improving light regime.

Besides determining the ability of the model to reproduce trends in phytoplankton species group composition we also desired to compare results of 2D-simulations with 3D-simulations. Although we were not able to execute 2D- and 3D-simulations for the same year using the same input we choose to compare between simulations of different years. The 2D-simulations were performed for the years 1991-1995 and the 3D simulations for the years 1996-2003. As previously remarked: these simulations not only differ in vertical mixing but also in meteorological forcing and river input. One of the results of this comparison is that in general 3D-simulations achieve better results for the computed species composition than 2D-simulations, not just in stratified areas but also in the complete Dutch coastal zone. For chlorophyll there is no significant difference between 2D and 3D results in the non-stratified areas. Originally, the BLOOM-module was developed and calibrated for 2D-modeling, but it turns out to be very suitable for 3D applications. Especially in stratified

areas only 3D-simulations might in the future lead to useful results on species composition and oxygen. However, 3D-simulations consume a lot of time, thus for each question it should be considered whether it will be necessary to run all simulations in 3D. In many cases 2D-simulations may still meet the needs of the project. Although not all inputs for the 2D- and 3D-simulations were exactly similar it is not likely that deviation in 2D and 3D results can be totally attributed to these differences. Based on our results it seems reasonable to conclude that 3D-simulations gain better results than 2D-simulations, even for stations close to the coast. However, it is recommended to repeat a comparison between results of 2D- and 3D-simulations for the same years with the same input except for the hydrodynamic forcing.

Several causes complicate comparison of monitoring data with model data. First, it seems that phytoplankton biomass for the different species groups is generally higher in the simulation outcomes compared to the monitoring data. This is more so for the 2D-simulations than the 3D-simulations. This can be due to the fact that in BLOOM only four species (and their subtypes) are incorporated, while under natural conditions more species are present in the system. However, available resources in the model appear to be an accurate representation of the amount of resources that will be available in the natural system. Total chlorophyll in the model approximately equals total chlorophyll as measured in the field, which becomes clear from the comparisons of modeled and measured chlorophyll. In the end this means that in the model the total amount of chlorophyll is divided over fewer species than present in a real system. Logically, these species have more resources to their disposal than species under natural conditions and as a result they reach higher biomasses. Another reason for higher biomasses in the model results compared to the measured biomasses may be caused by an underestimation of algal counts.

A second thing that complicates data interpretation, in this case predominantly of the monitoring data, is the fact that the measurements are taken at a single point and at a certain time. This results in a low number of measurements during the blooming period, which in some cases is fairly short, only one or two months. In this short period sometimes only one or two measurements are taken. Smaller autumn blooms might even be totally missed. This makes it hard to detect significant trends in the measurement data. Next to the small number of measurements during blooming periods, variation between these measurements is considerably higher during blooming periods than in periods when no blooms occur. This variation between years during the blooming period is possibly caused by differences in abiotic factors such as temperature or nutrient availability, that influence the onset of the bloom. These variations in the onset of the blooming period create a lot of variation over years in the months around the blooming period. Another cause of high variation during the months when algal blooms occur possibly is the spatial nature of the blooms. Some blooms, such as for dinoflagellate species in the open sea, are shown to be rather patchy (Ospar workshop 2007). These patches of high algal concentrations move along with the tide. So at the single point in time when the measurement is taken its algal concentrations depend on whether the sample is taken inside the patch or just outside it. A solution for this problem is placement of a measurement buoy that measures continuously. Preliminary results from the buoy at the Oyster Grounds presented during the Ospar Workshop of 2007 indeed showed that these patches occur. Concluding, high variation and few measurements during blooming periods complicate comparison of model results with monitoring data.

A third and last problem that arises during data analysis is picking an appropriate method to compare model and monitoring results. In this study a cost function was used. However, this method has several disadvantages. To begin with standard deviations are created for monitoring data and used to compare model results with. However, these standard deviations represent the variation in the data for a certain month and between years. These standard deviations for separate months are finally summarized into a single standard deviation for a certain species group at a certain station. So, within year variation is included as well. This generates a rather large standard deviation which makes it easier to obtain good results when comparing with model data. However, on the other side it seems reasonable to account for variation in monitoring data once comparing with a model outcome. Determining cost functions for more specific amounts of data, such as comparing each species at each station for each month is practically impossible, as there is too little monitoring data for each station in each month. Once a standard deviation cannot be determined, the cost function can not be calculated. It would be worthwhile to explore some alternatives for calculating cost functions and develop possibilities to compile a general routine for the most appropriate way to make a quantitative comparison between model output and monitoring data. For starters, it would be useful to develop a routine that allows calculating cost functions over more specific and smaller time intervals. Now, lumping of standard deviations of monitoring data between and within years creates lower cost functions. More specific and shorter time intervals create stricter criteria, which in some cases might be preferred.

6 Conclusions

GEM including BLOOM has been validated extensively both in its 2D and more recently in its 3D version with respect to its main outputs (dissolved nutrients, oxygen, chlorophyll, extinction coefficient). Illustration of the performance of recent applications may be found Los et al. (2008) and in Blaas et al. (2007). In the current report the first validation of species group outputs are presented. Although the goodness of fit according to the cost function and graphical comparison with measurements is not (yet) at the same level as for the aforementioned outputs, BLOOM shows promising results. General model results for non-stratified stations correspond rather well with the monitoring data. It seems that the model has a better capability to detect general trends, such as a seasonal trend for each species group, and that model results deviate more once trying to predict regional patterns or more local phenomena. It can be concluded that several aspects of the BLOOM module would benefit from a more thorough examination. Especially deviations in stratified areas need a more thorough examination of other model aspects, such as vertical mixing. This may result in improved parameterization (recalibration) or even modification of some parts of the BLOOM module.

Our main conclusions are:
-Diatoms are predicted most accurately of all species groups
-*Phaeocystis* is in general predicted rather accurately, except for stratified areas
-Modeling of dinoflagellates and flagellates needs improvement
-3D-modeling of stratified areas needs improvement
-3D-models give a better prediction of species composition than 2D-models
-It is recommended to examine the possibilities for developing a standard routine for comparing model data and measurement data

General trends, such as the occurrence of diatoms throughout the North Sea, are reproduced correctly in the model. Model predictions of diatoms biomass correspond best with the data,. Modeling of dinoflagellates and flagellates still could use significant improvement. Prediction of these species groups is more accurate using 3D-simulations compared to 2D simulations. In 2D-simulations, dinoflagellates are abundant everywhere, while in the 3D-simulations they are more abundant in offshore areas, which corresponds better with the reality. To improve results for modeling of dinoflagellates special points of attention for dinoflagellates can possibly be:
1. A reduction of the maximum growth rates, which are higher than measured,
2. Including mixotrophic growth. This option is implemented, but this process is not yet used in the standard GEM set-up,
3. Implementing buoyancy control in case the turbulence is sufficiently low. Possibilities to do so exist, as a stable, operational 3D version of GEM now exists.

In general, 3D-simulations gain better results for all species, both in stations near the coast and offshore stations. To obtain a better comparison of 2D- and 3D-modeling it is recommended to run identical simulations for the same years in both 2D and 3D. An improvement for stratified areas encompasses the occurrence of *Phaeocystis*. Given the explanation presented for this behavior in the previous chapter, it is not known in advance

whether the solution can be obtained by an improved description of vertical mixing at the onset of stratification, or if the biological characteristics of *Phaeocystis* should be modified as well.

Overall, making a precise comparison of model outcomes with monitoring data is complicated due to several reasons. Model data might slightly overestimate phytoplankton biomass, due to the fact that all available resources are used by the modeled species, while monitoring might slightly underestimate phytoplankton biomass. Further, most methods for making quantitative comparisons of model data and monitoring data are under discussion. The cost function method that was used in this report has several disadvantages, and further exploration of ways to improve this essential part of model validation would be valuable.

In this study we chose to examine trends in measurement and model data for several stations and for each year separately. We validated the model for its output concerning four different groups of species for each specific station by comparing cost functions and we examined where large deviations between model and monitoring data occurred. We refrained from looking at specific trends in species group composition over a large time span. However, one of the functional future applications of BLOOM could be predicting species group composition as a result of changes in abiotic steering parameters, such as a rise in temperature. Another attractive future use of BLOOM will be ‘real time’ forecasting. Therefore, improvements in the capacity of BLOOM to predict species composition are urgently needed.

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A Figures

Figure A 1.1 Trends for data and a 2D-simulation of three species groups and one species in 1991 at a nearshore (Noordwijk 10) and an offshore station (Noordwijk 70).

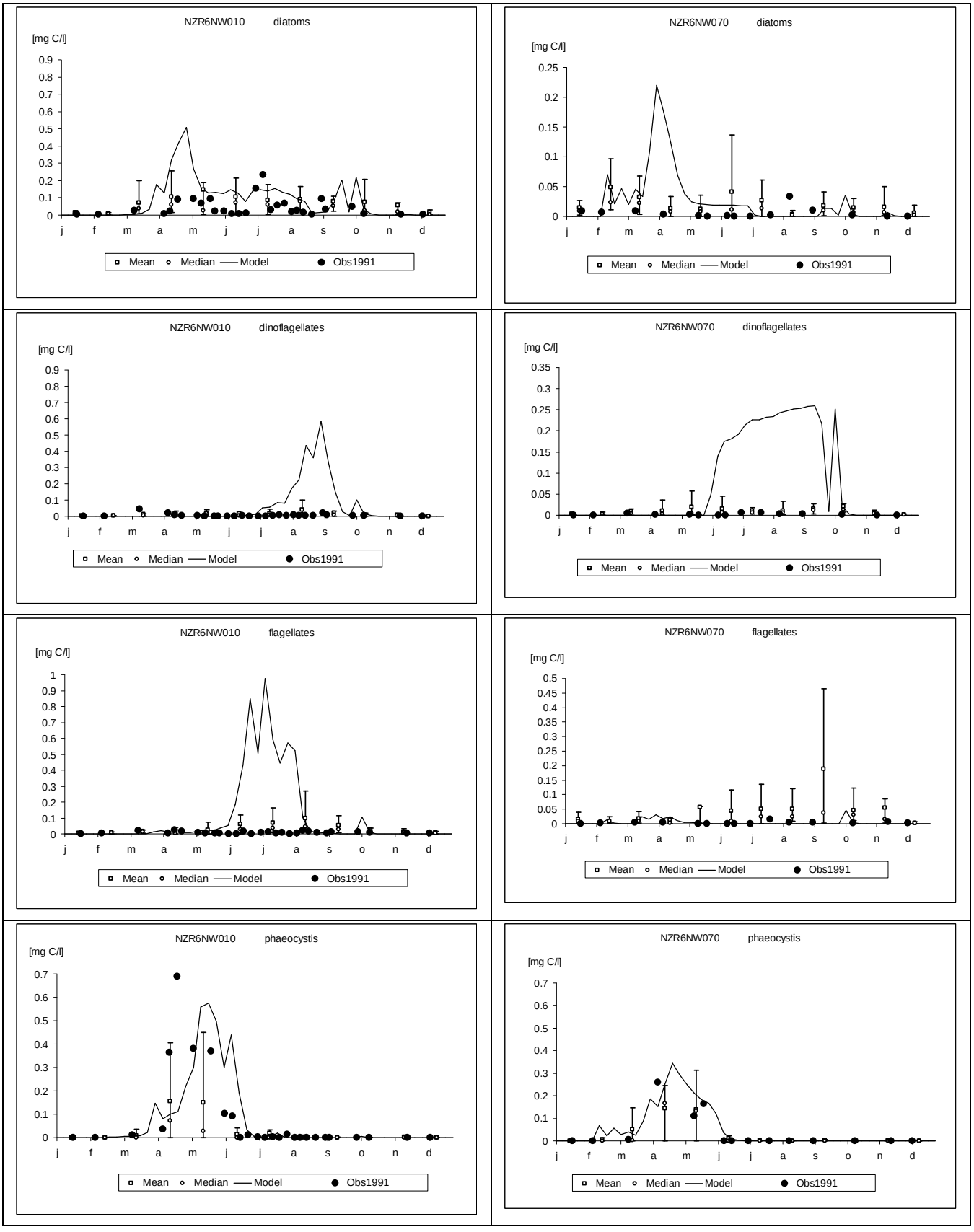


Figure A 1.2 Trends for data and a 2D-simulation of three species groups and one species in 1992 at a nearshore (Noordwijk 10) and an offshore station (Noordwijk 70).

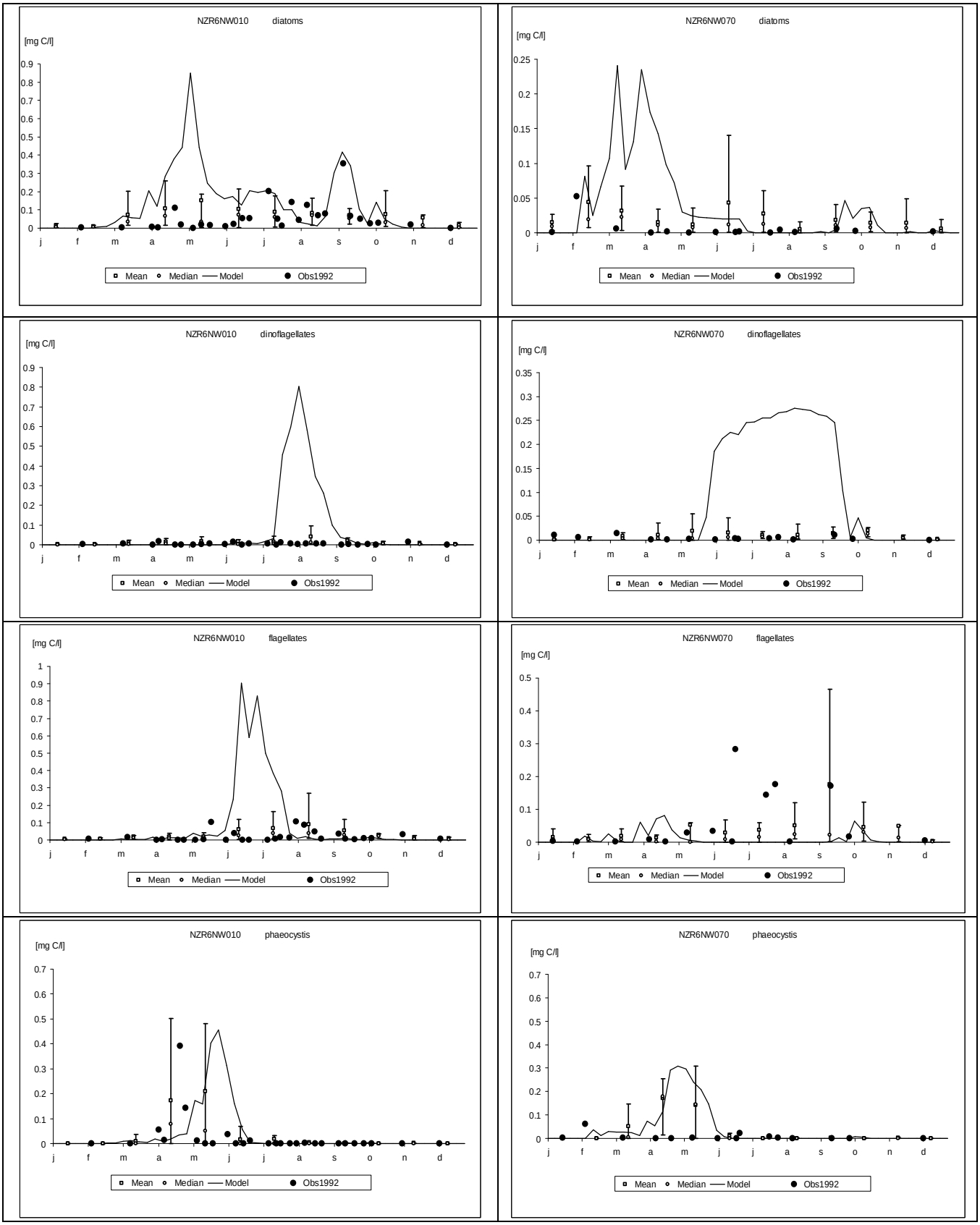


Figure A 1.3. Trends for data and a 2D-simulation of three species groups and one species in 1993 at a nearshore (Noordwijk 10) and an offshore station (Noordwijk 70).

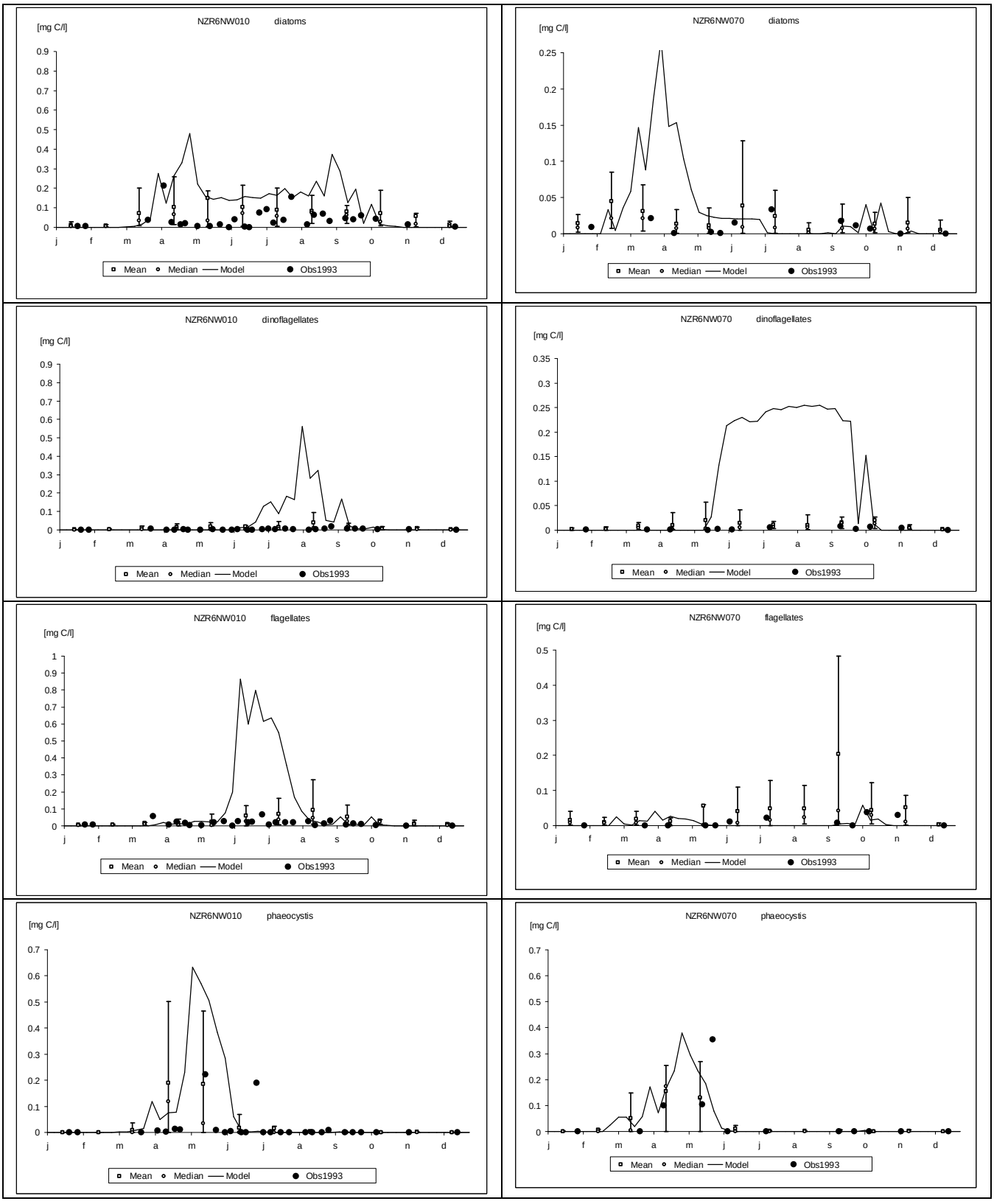


Figure A 1.4. Trends for data and a 2D-simulation of three species groups and one species in 1994 at a nearshore (Noordwijk 10) and an offshore station (Noordwijk 70).

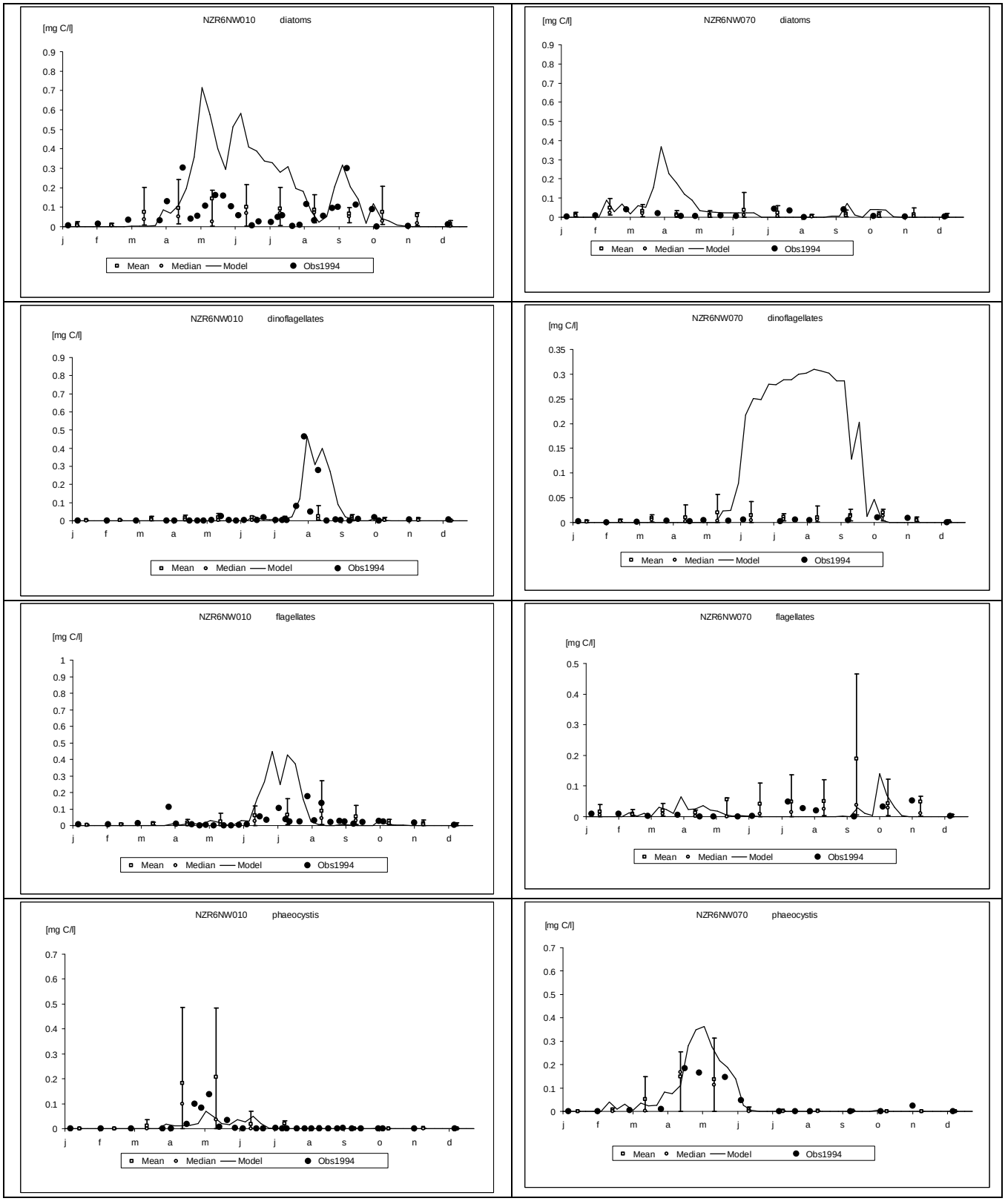


Figure A 1.5. Trends for data and a 2D-simulation of three species groups and one species in 1995 at a nearshore (Noordwijk 10) and an offshore station (Noordwijk 70).

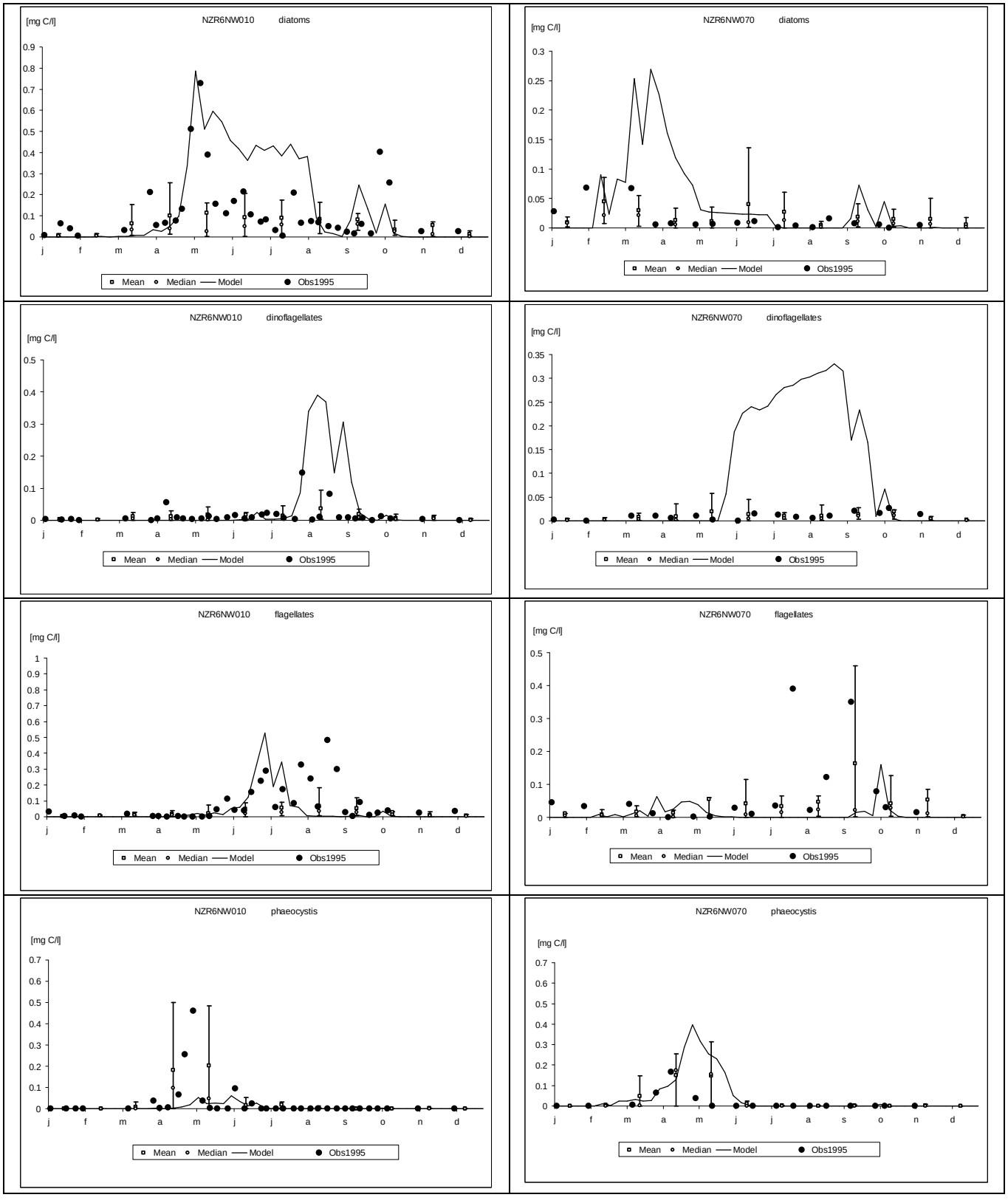


Figure A 1.6. Trends for data and a 3D-simulation of three species groups and one species in 1996 at a nearshore (Noordwijk 10) and an offshore station (Noordwijk 70).

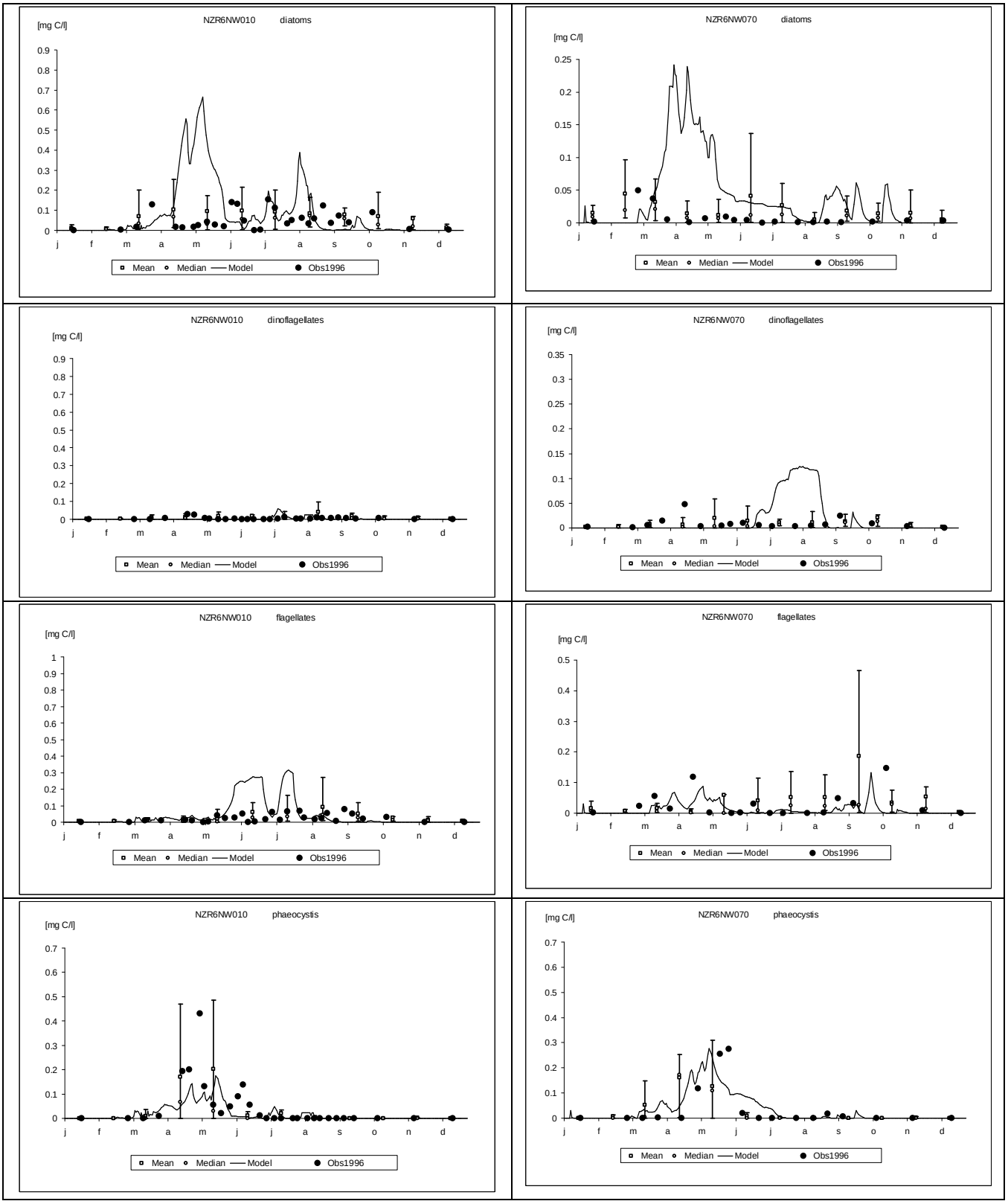


Figure A 1.7. Trends for data and a 3D-simulation of three species groups and one species in 1997 at a nearshore (Noordwijk 10) and an offshore station (Noordwijk 70).

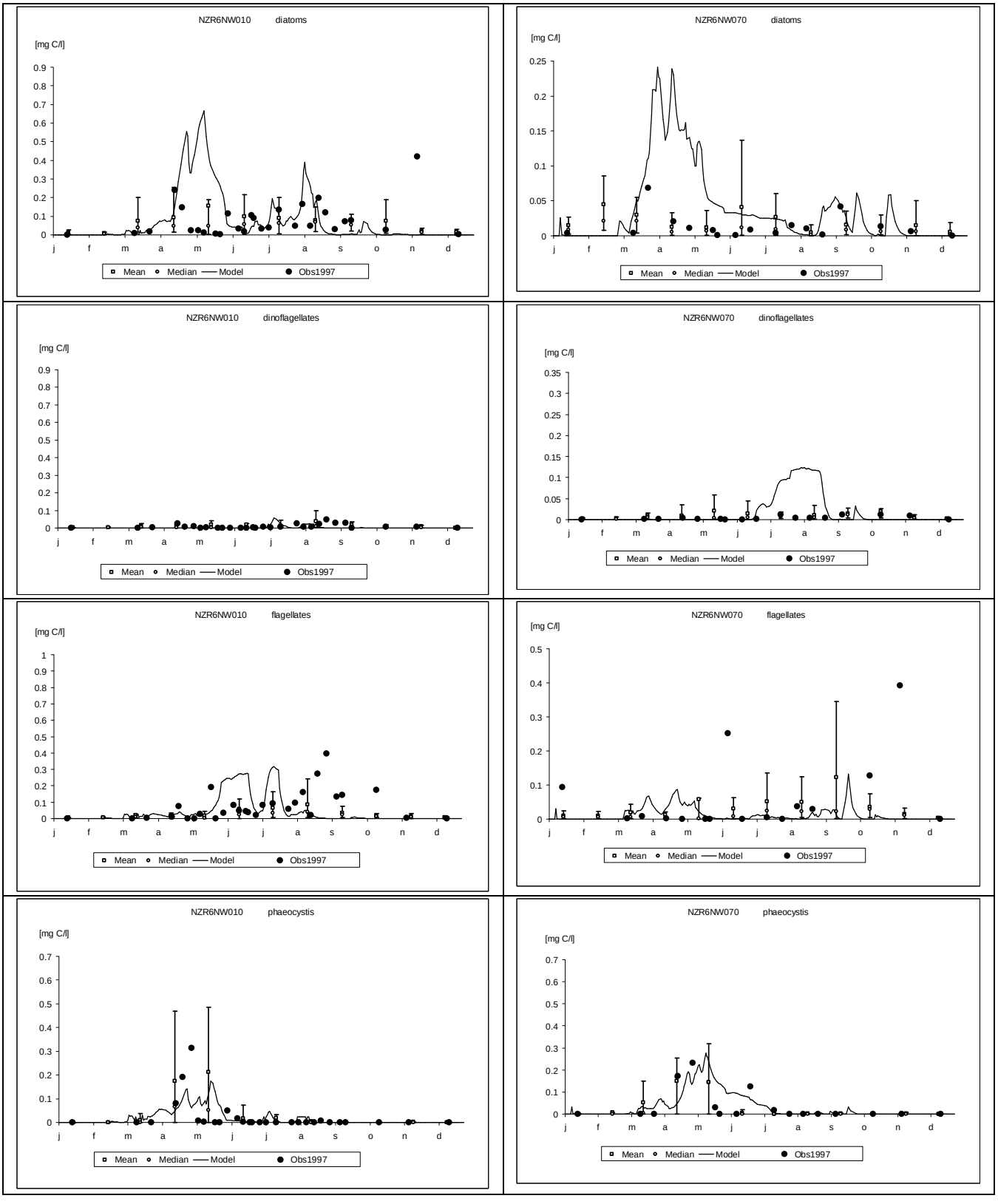


Figure A 1.8. Trends for data and a 3D-simulation of three species groups and one species in 1998 at a nearshore (Noordwijk 10) and an offshore station (Noordwijk 70).

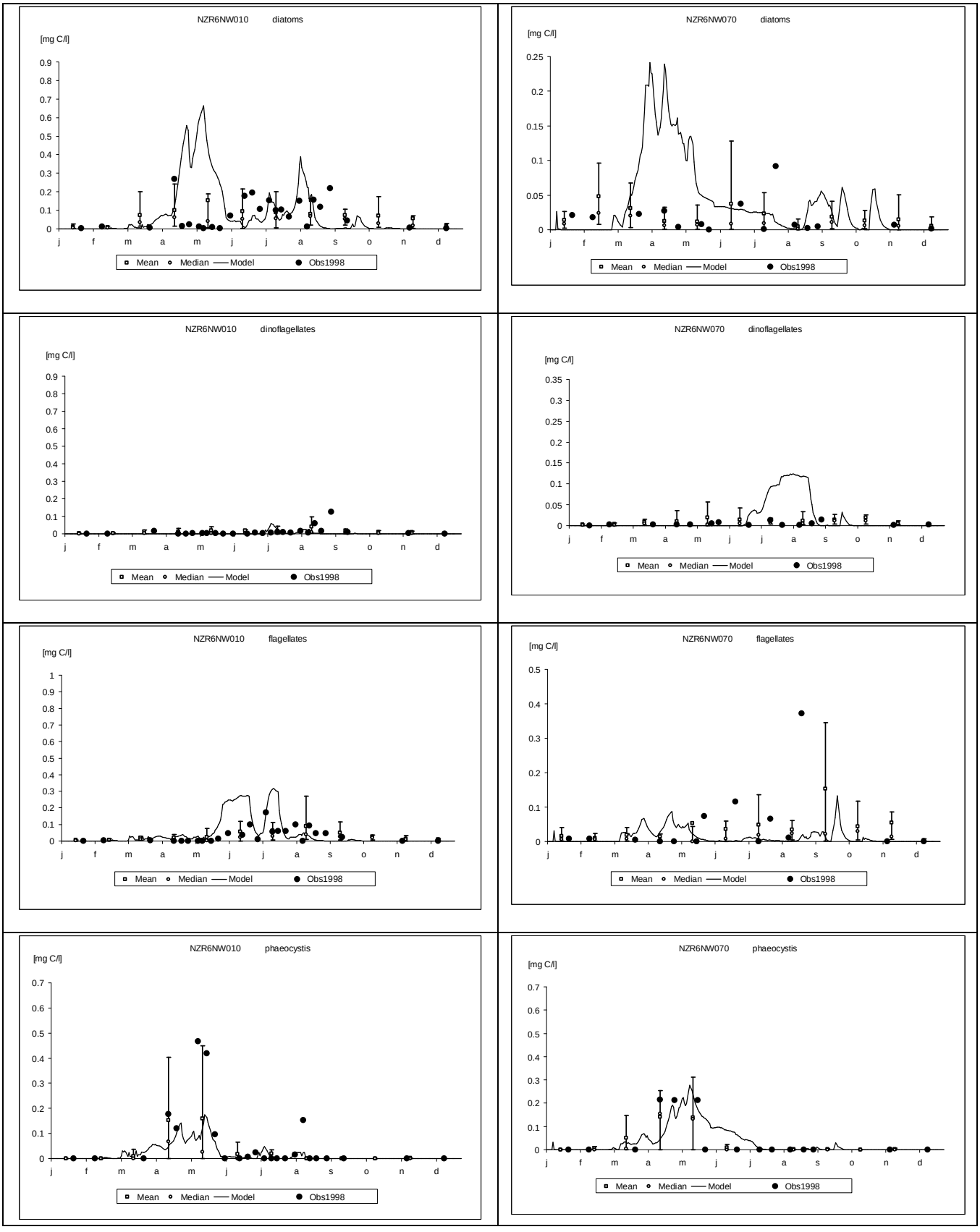


Figure A 1.9. Trends for data and a 3D-simulation of three species groups and one species in 1999 at a nearshore (Noordwijk 10) and an offshore station (Noordwijk 70).

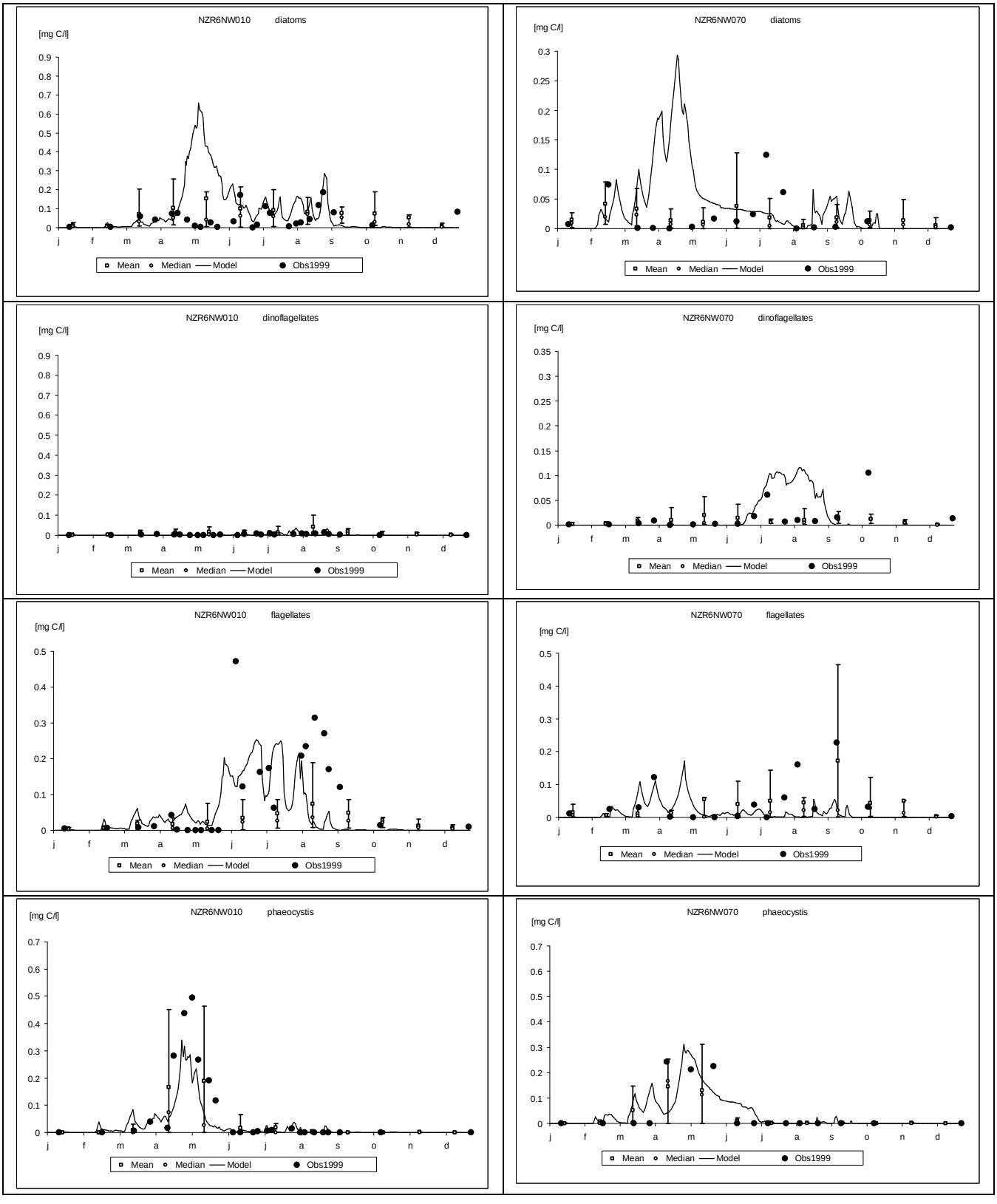


Figure 1.10. Trends for data and a 3D-simulation of three species groups and one species in 2000 at a nearshore (Noordwijk 10) and an offshore station (Noordwijk 70).

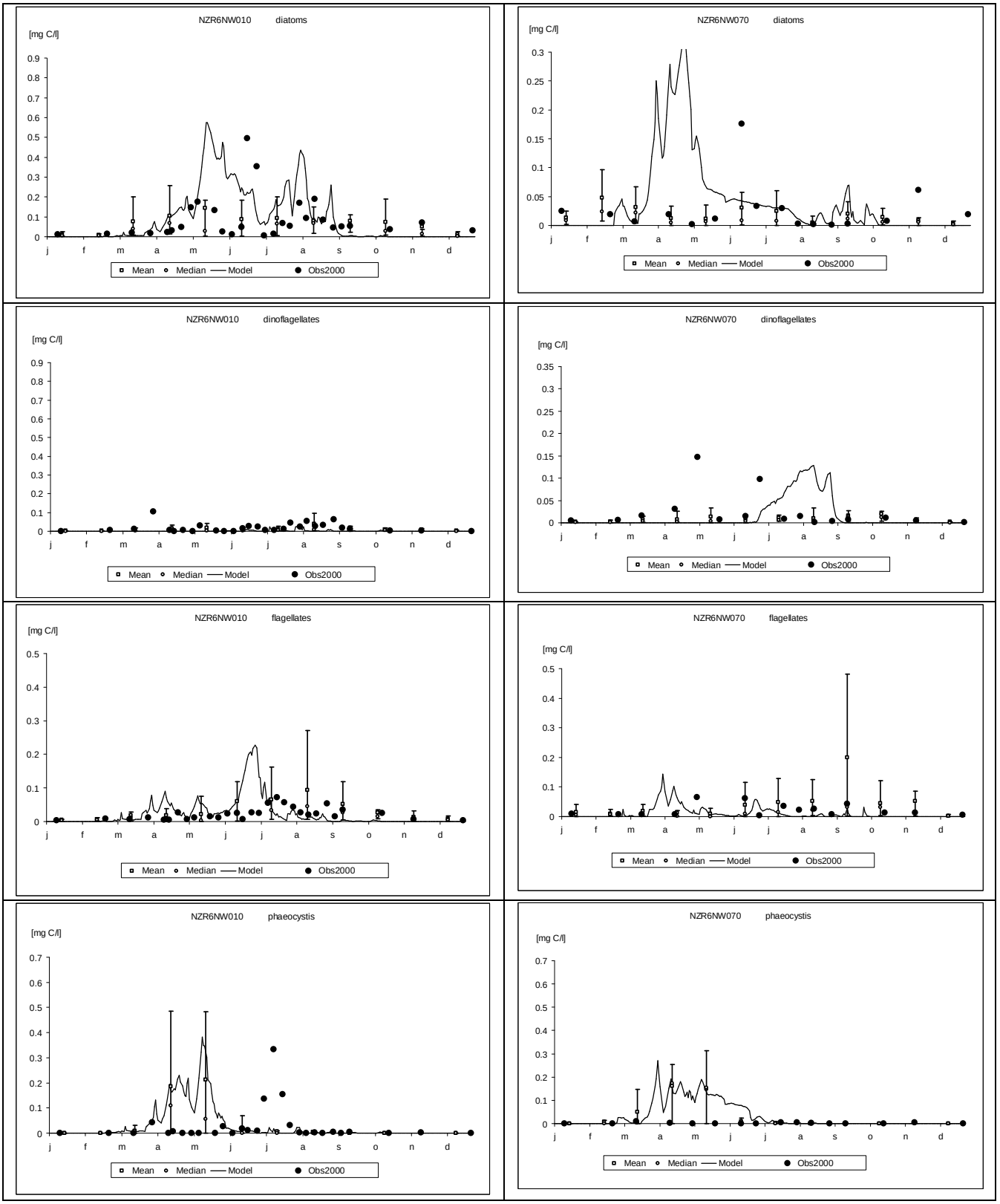


Figure A 1.11. Trends for data and a 3D-simulation of three species groups and one species in 2001 at a nearshore (Noordwijk 10) and an offshore station (Noordwijk 70).

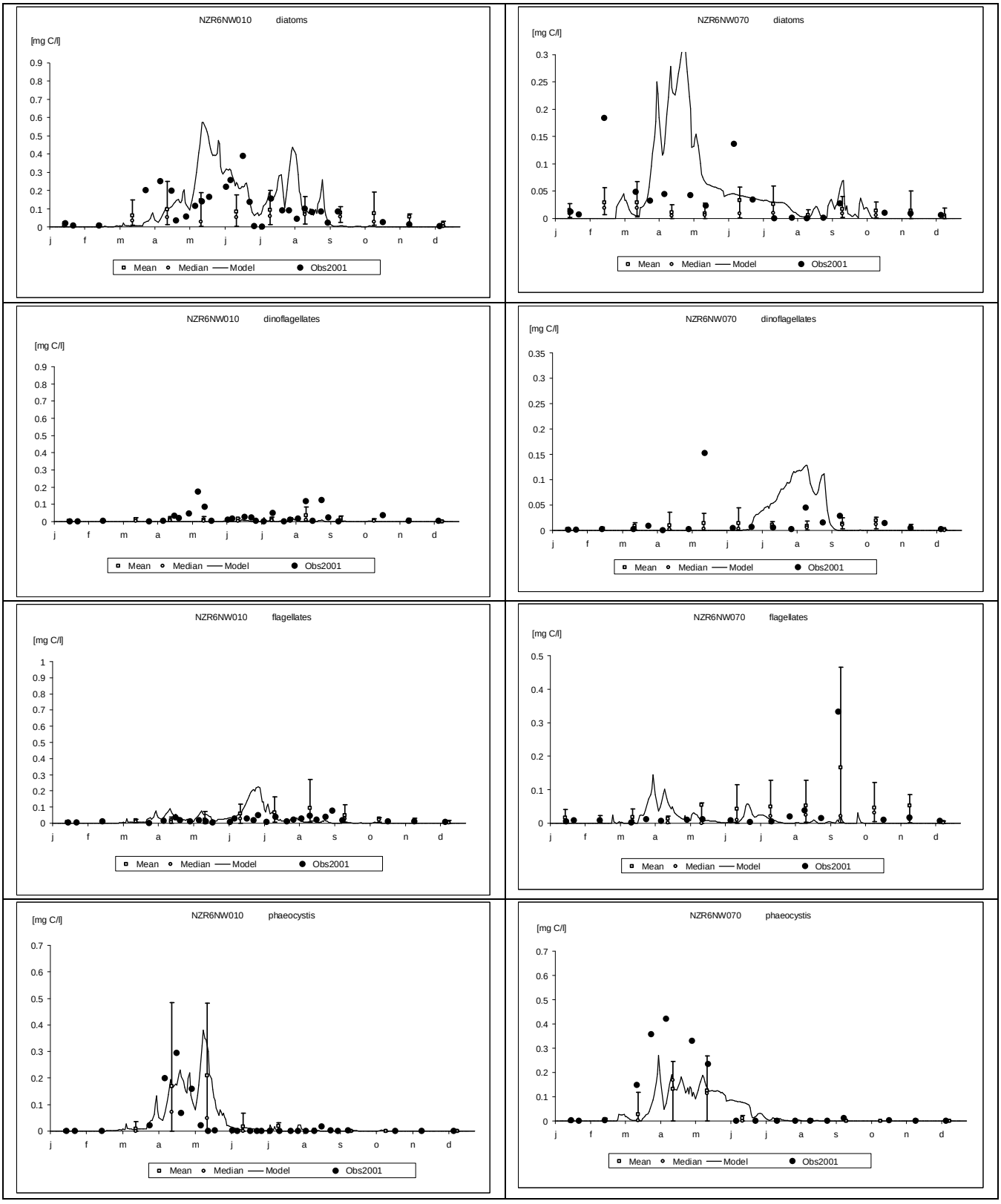


Figure A 1.12. Trends for data and a 3D-simulation of three species groups and one species in 2002 at a nearshore (Noordwijk 10) and an offshore station (Noordwijk 70).

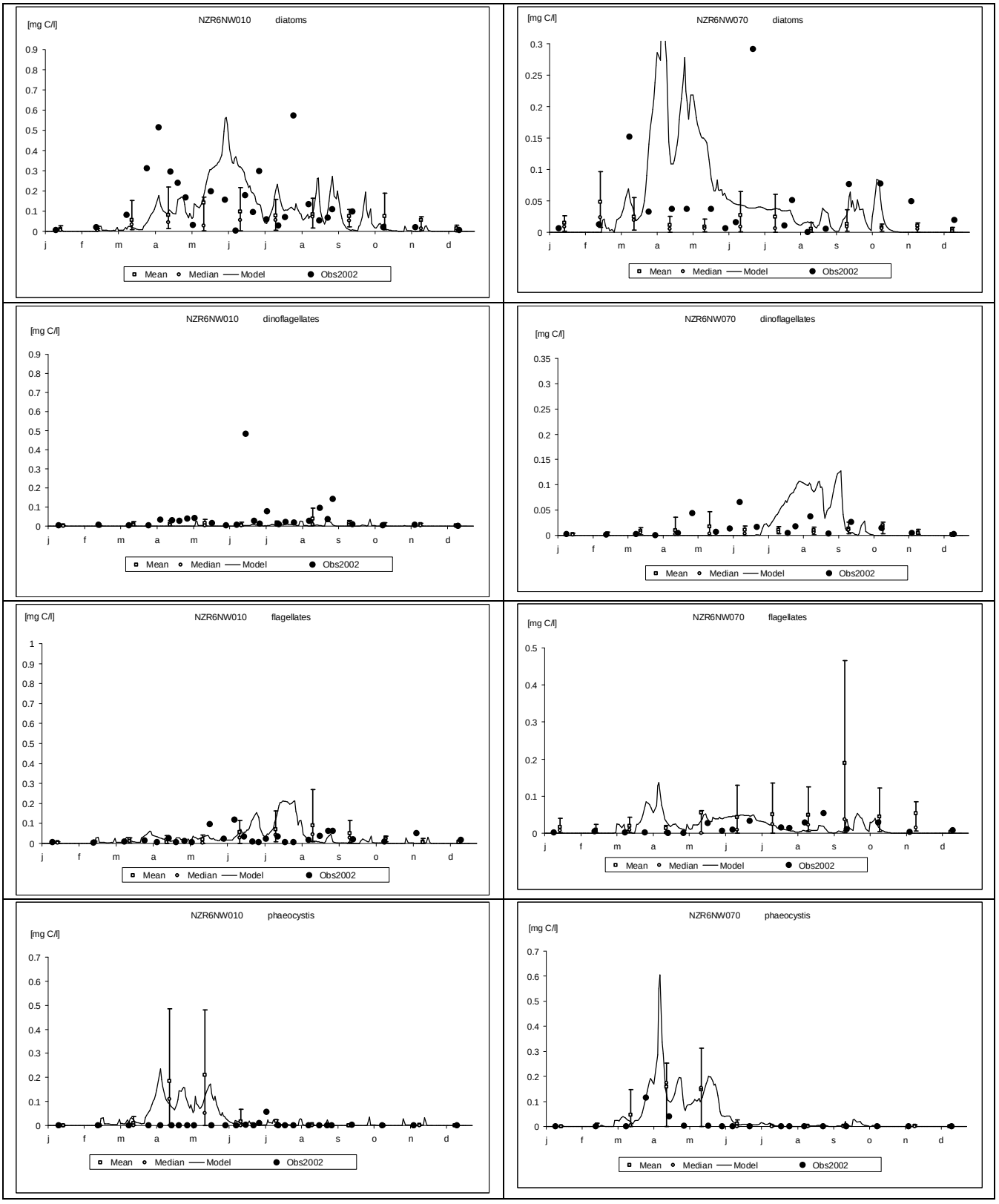


Figure A 1.13. Trends for data and a 3D-simulation of three species groups and one species in 2003 at a nearshore (Noordwijk 10) and an offshore station (Noordwijk 70).

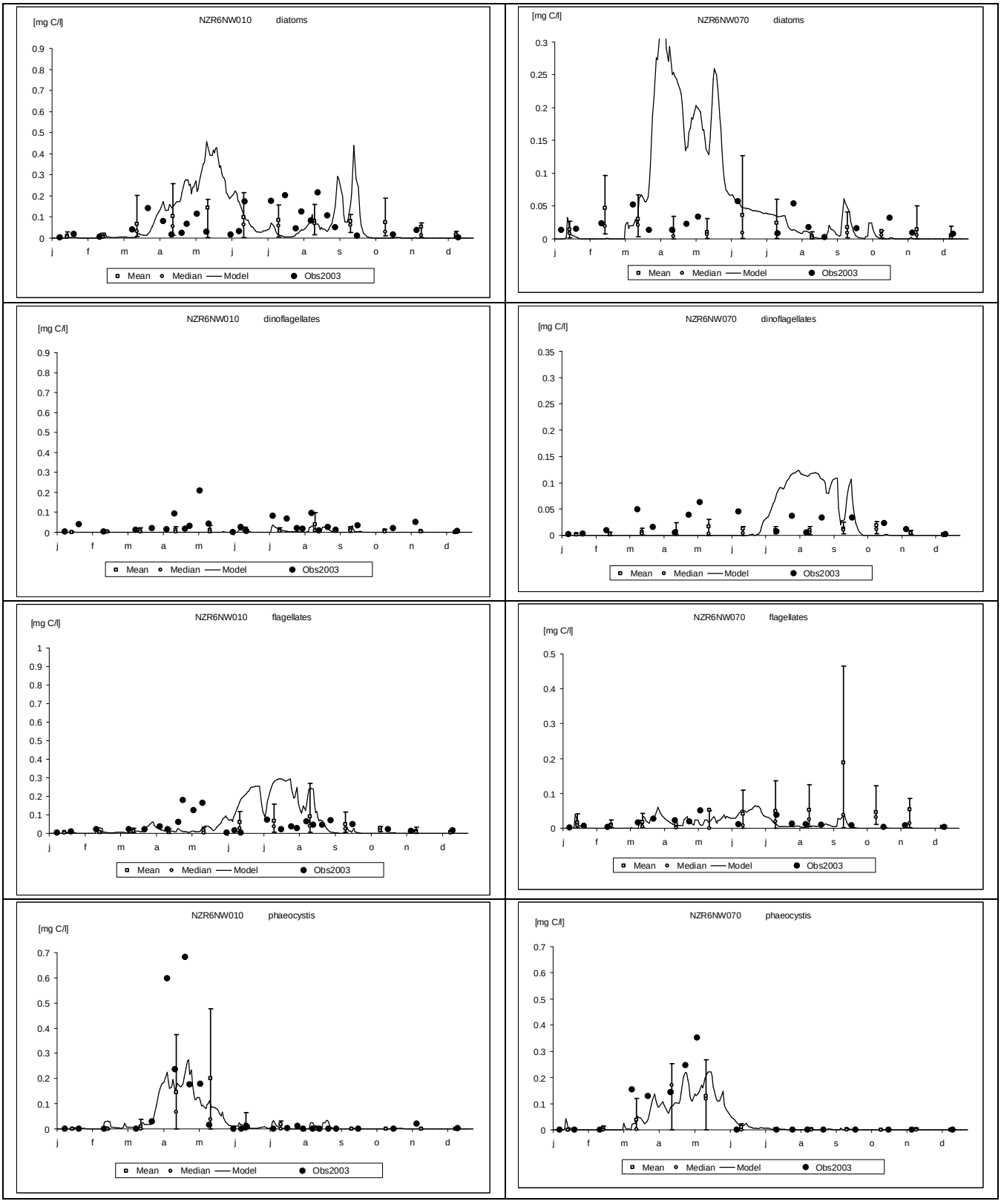


Figure A 2.1. Trends for data and a 2D-simulation of three species groups and one species in 1993 at Terschelling 135 and Terschelling 235.

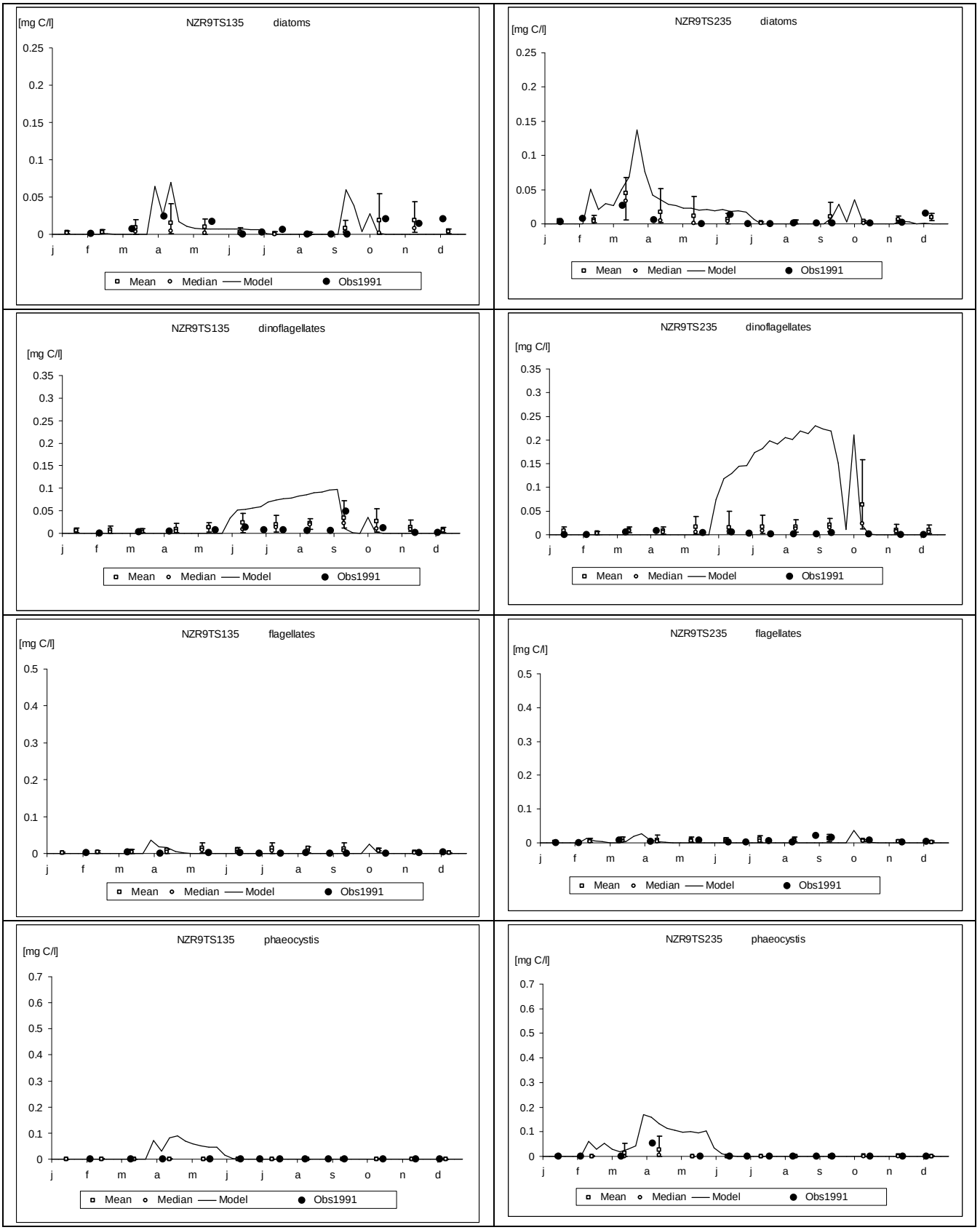


Figure A 2.2. Trends for data and a 2D-simulation of three species groups and one species in 1994 at Terschelling 135 and Terschelling 235.

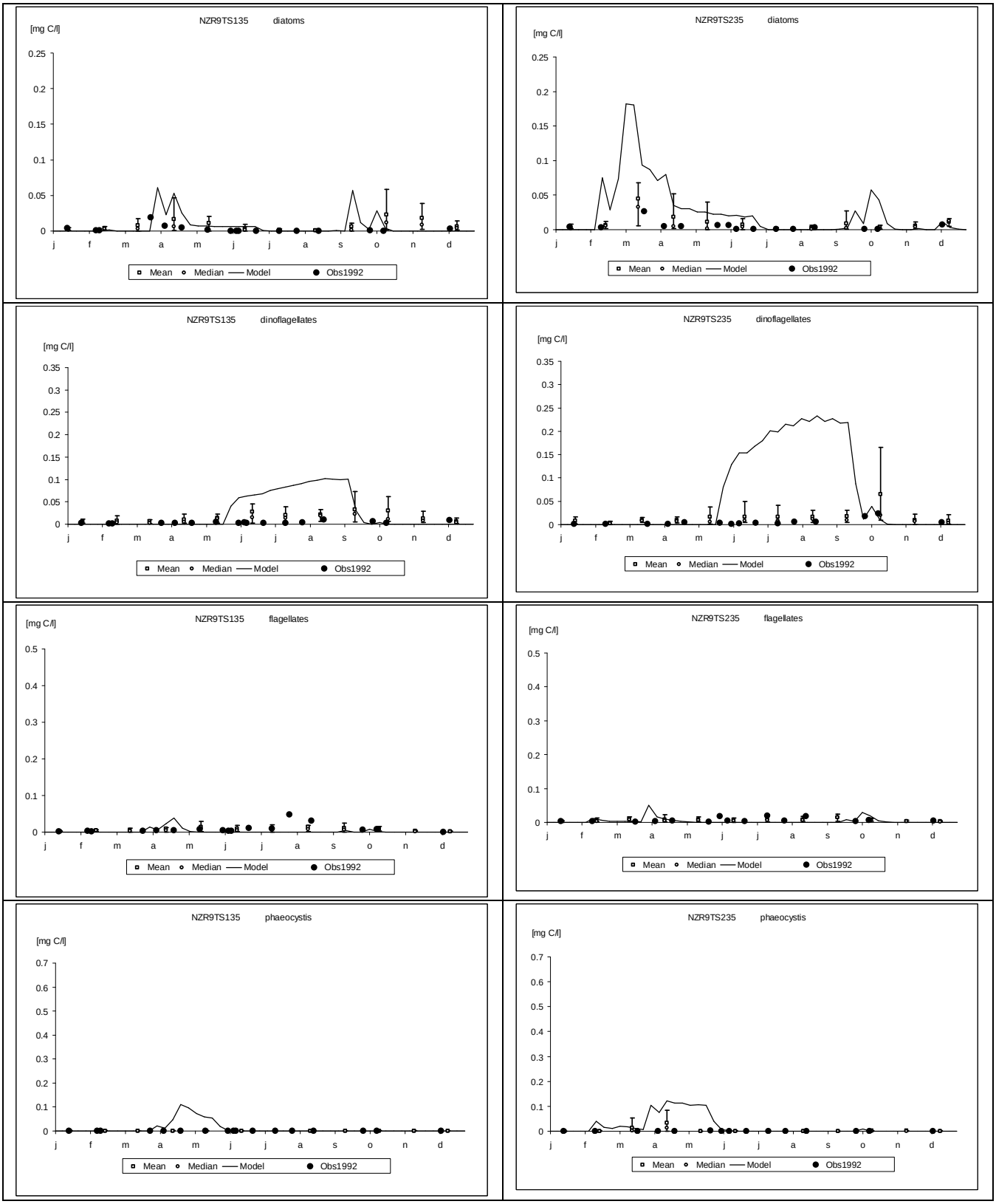


Figure A 2.3. Trends for data and a 2D-simulation of three species groups and one species in 1993 at Terschelling 135 and Terschelling 235.

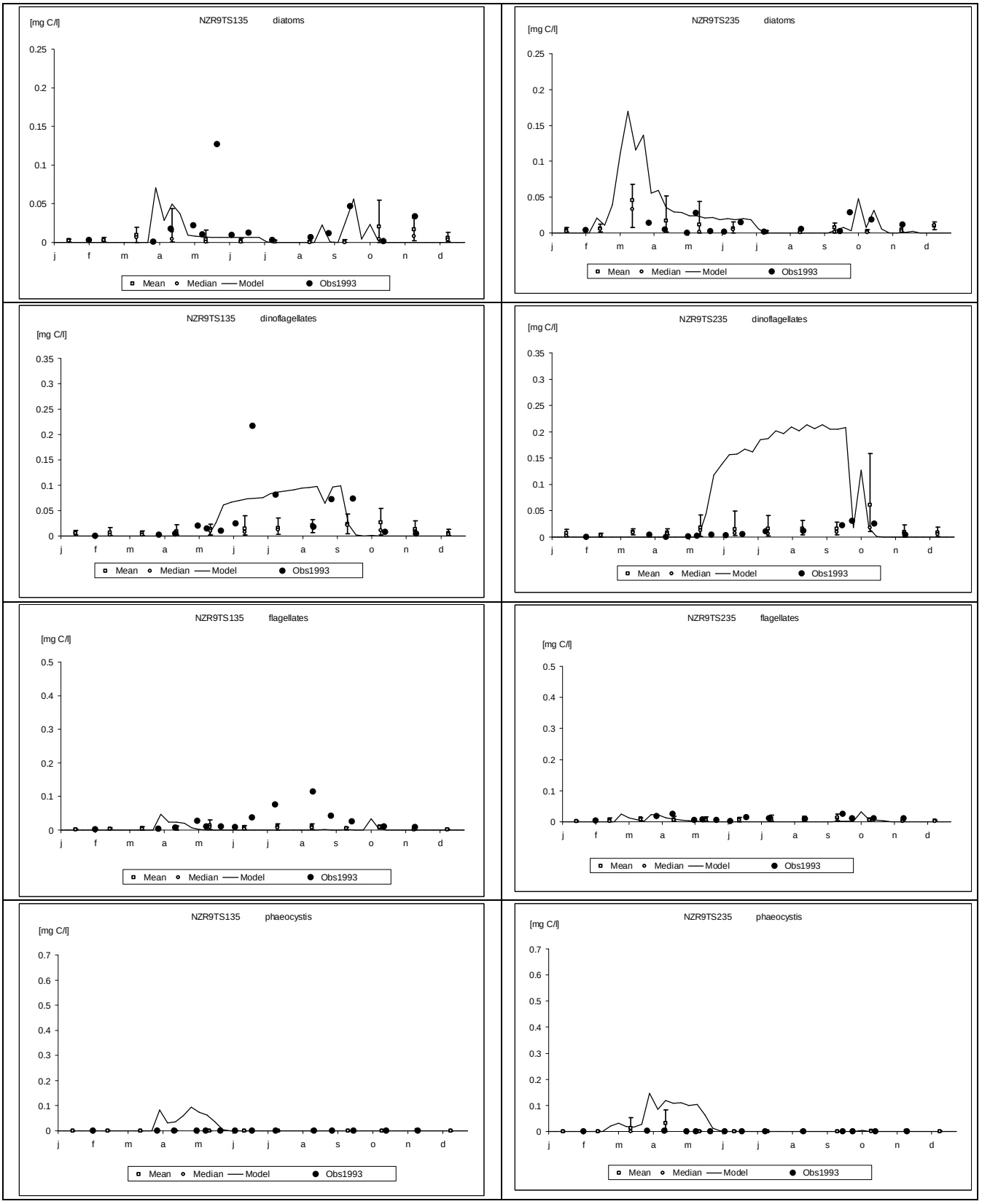


Figure A 2.5. Trends for data and a 2D-simulation of three species groups and one species in 1994 at Terschelling 135 and Terschelling 235.

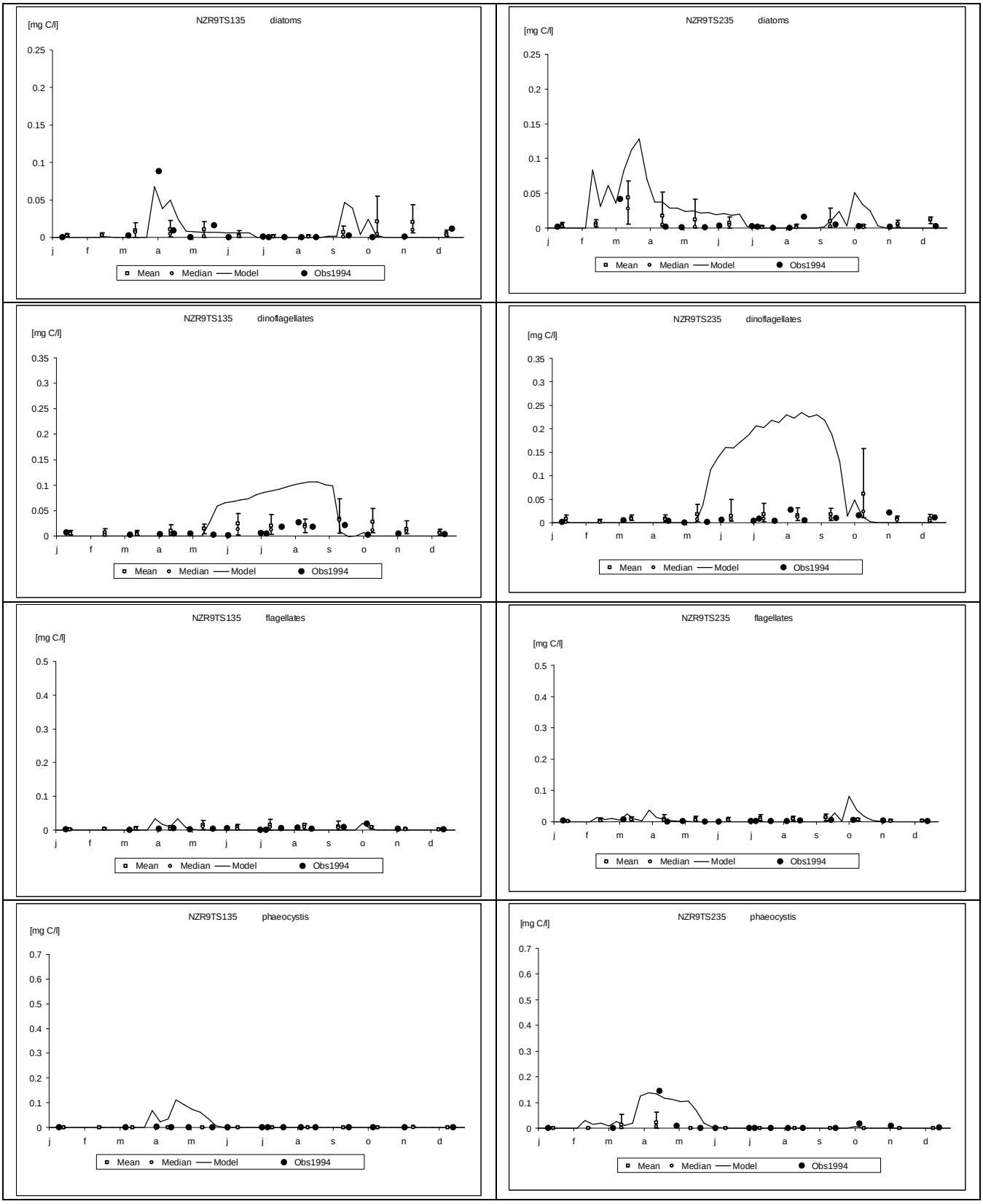


Figure A 2.4. Trends for data and a 2D-simulation of three species groups and one species in 1995 at Terschelling 135 and Terschelling 235.

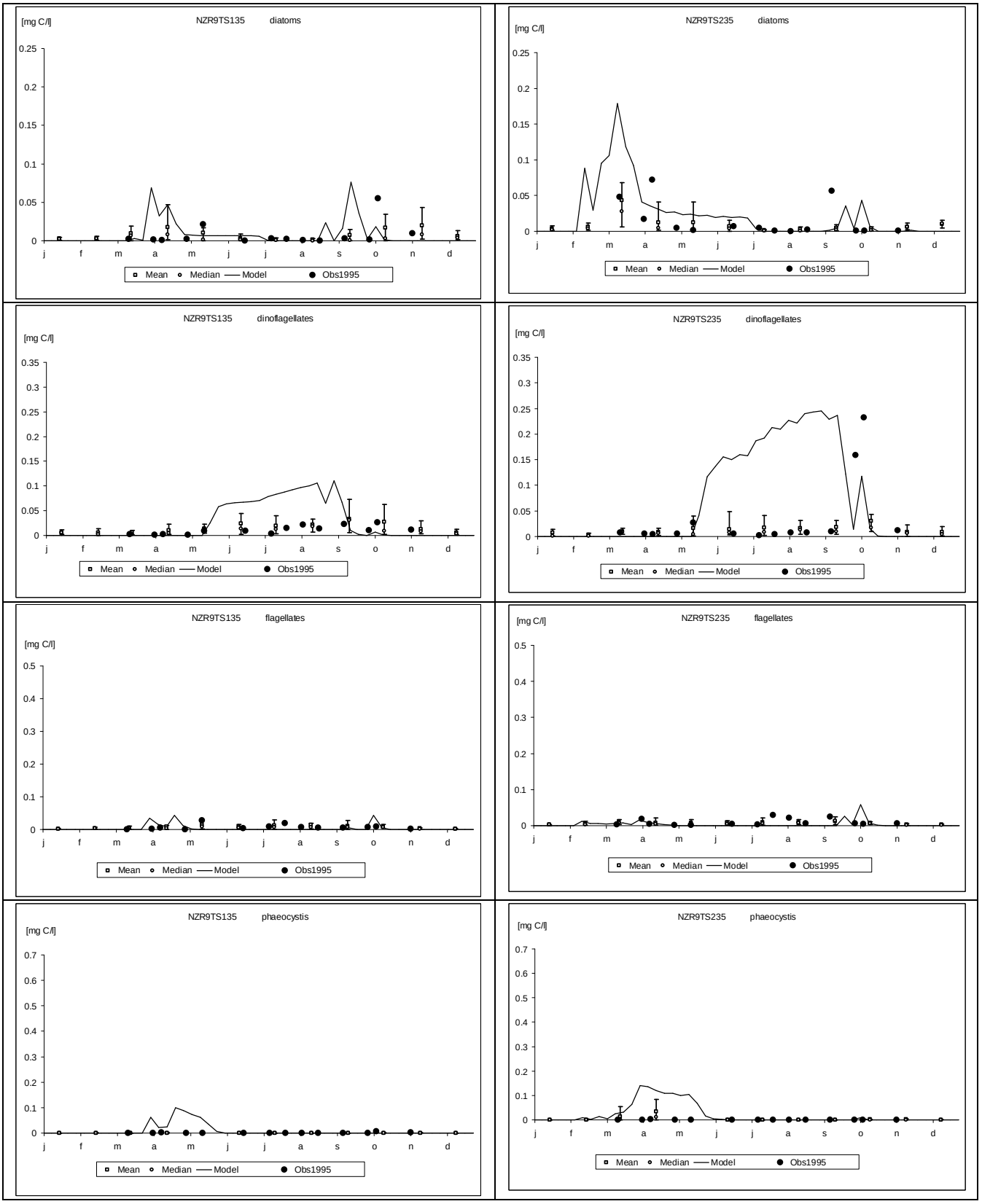


Figure A 2.6. Trends for data and a 3D-simulation of three species groups and one species in 1996 at Terschelling 135 and Terschelling 235.

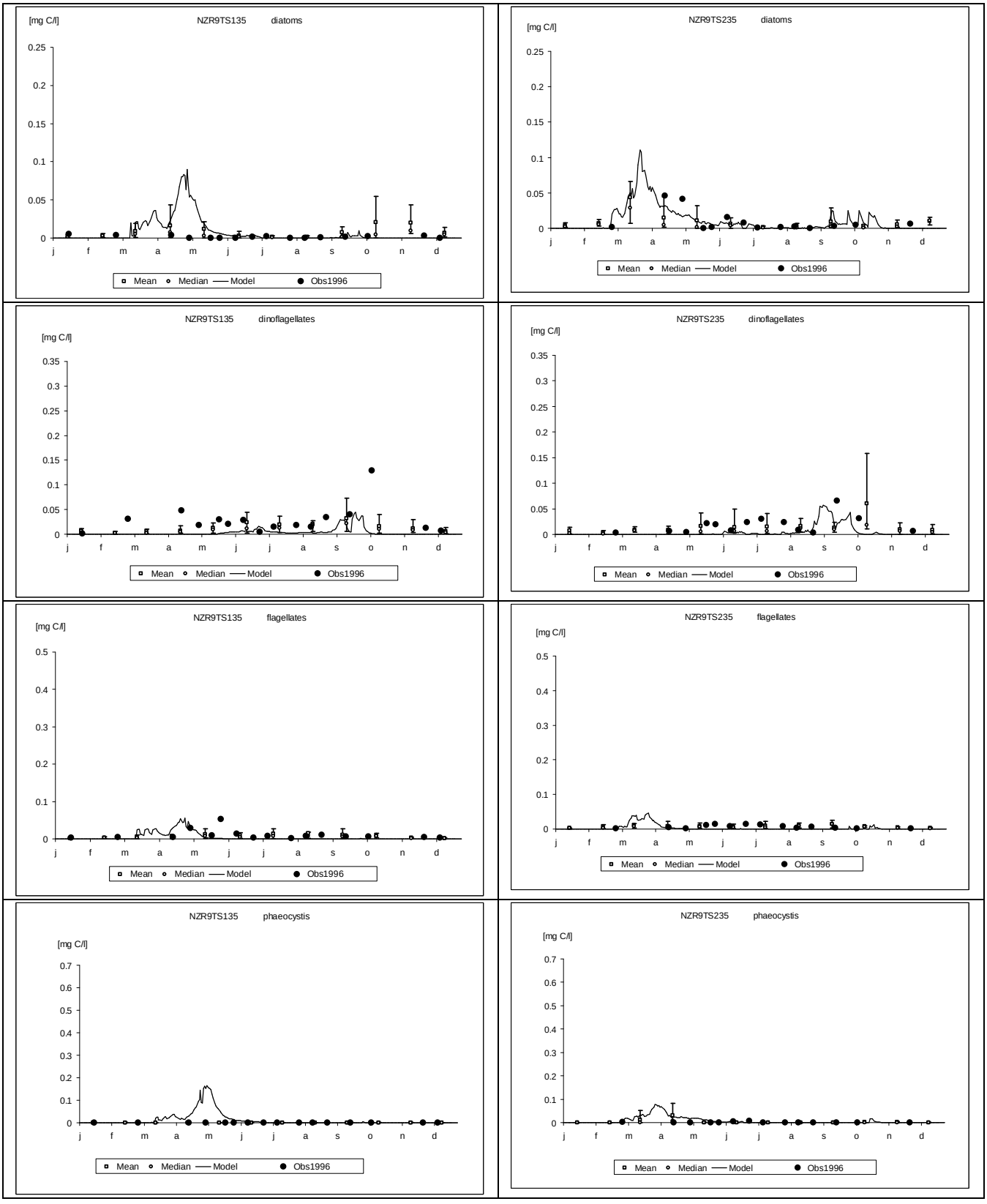


Figure A 2.7. Trends for data and a 3D-simulation of three species groups and one species in 1997 at Terschelling 135 and Terschelling 235.

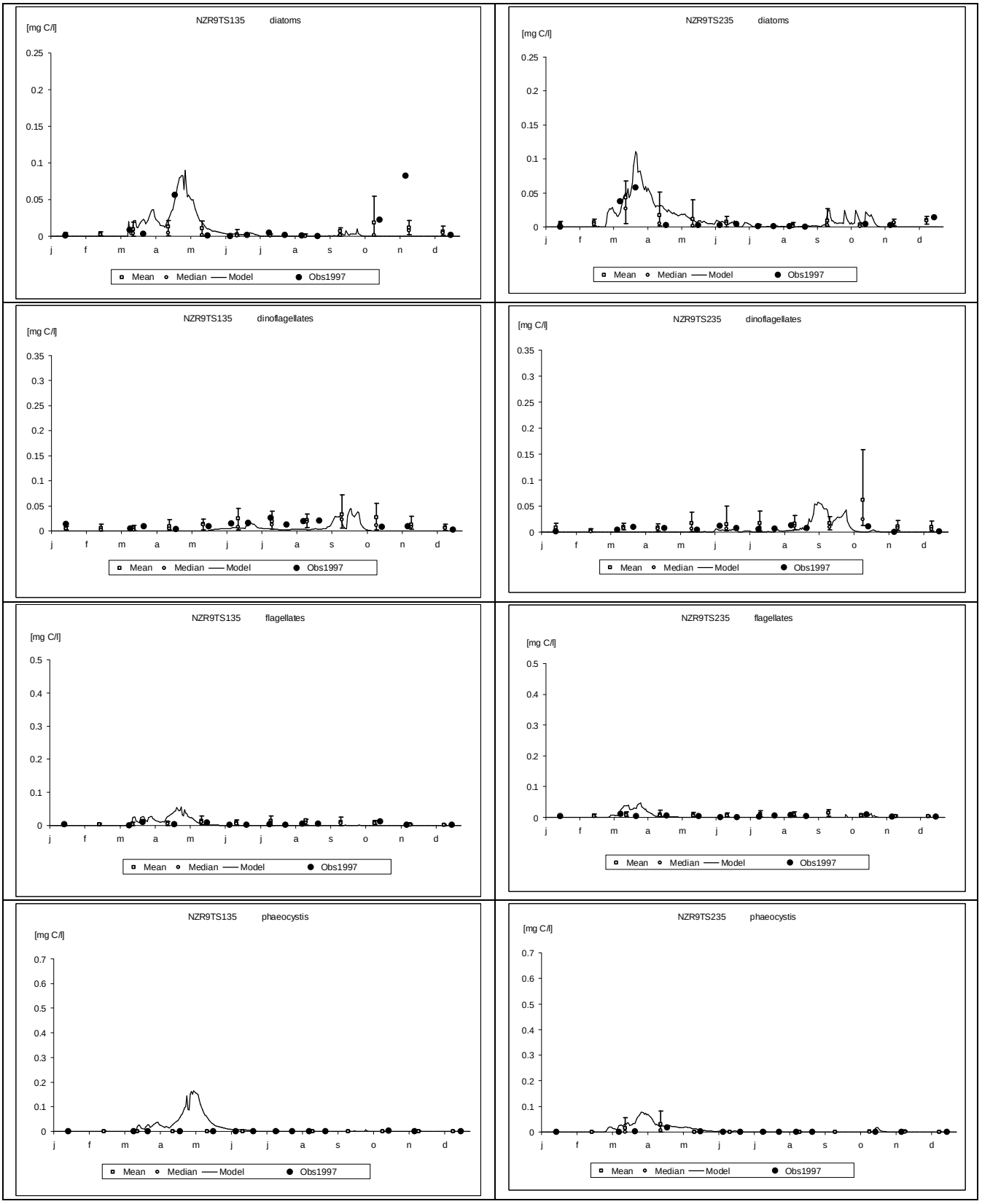


Figure A 2.8. Trends for data and a 3D-simulation of three species groups and one species in 1998 at Terschelling 135 and Terschelling 235.

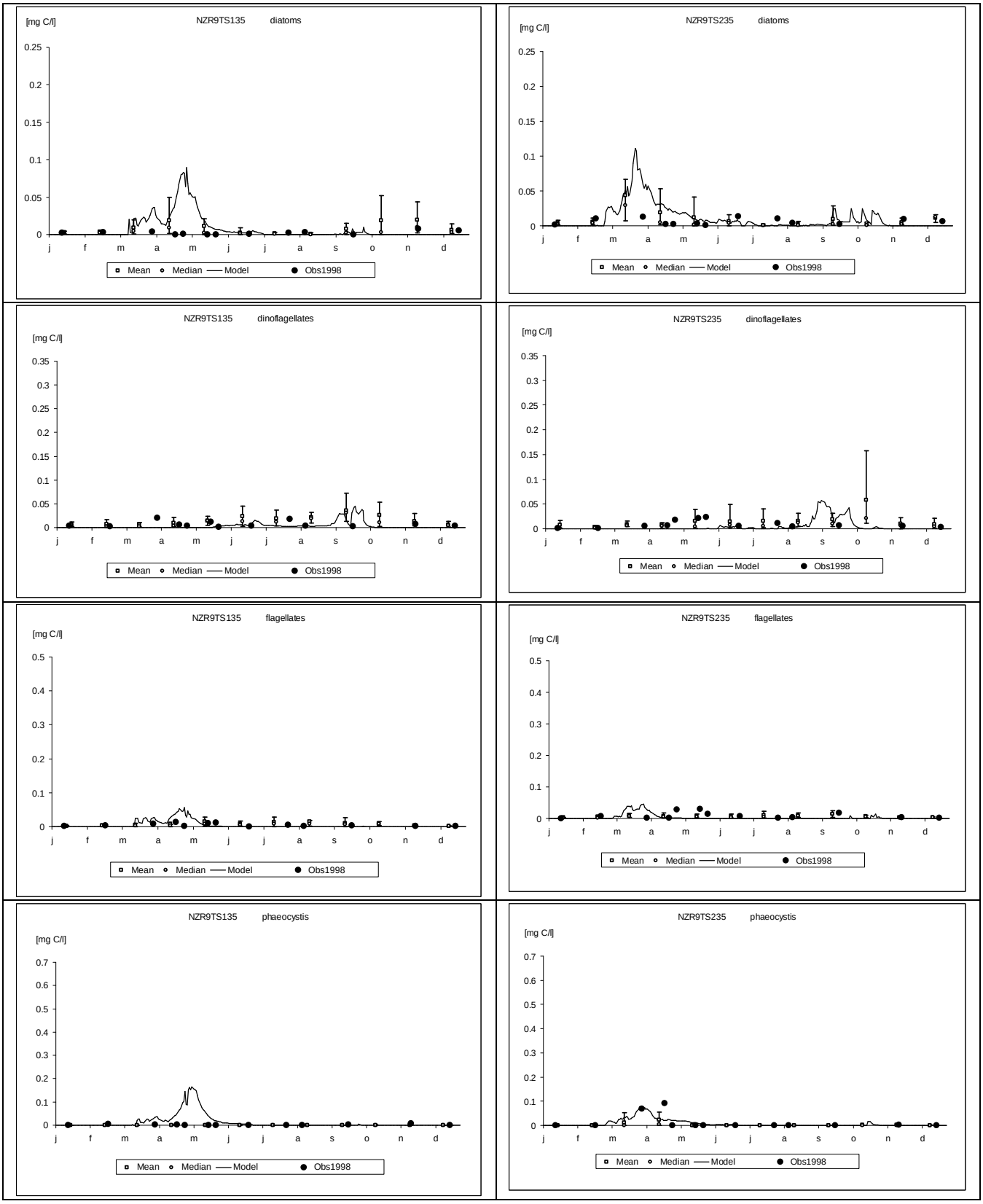


Figure A 2.9. Trends for data and a 3D-simulation of three species groups and one species in 1999 at Terschelling 135 and Terschelling 235.

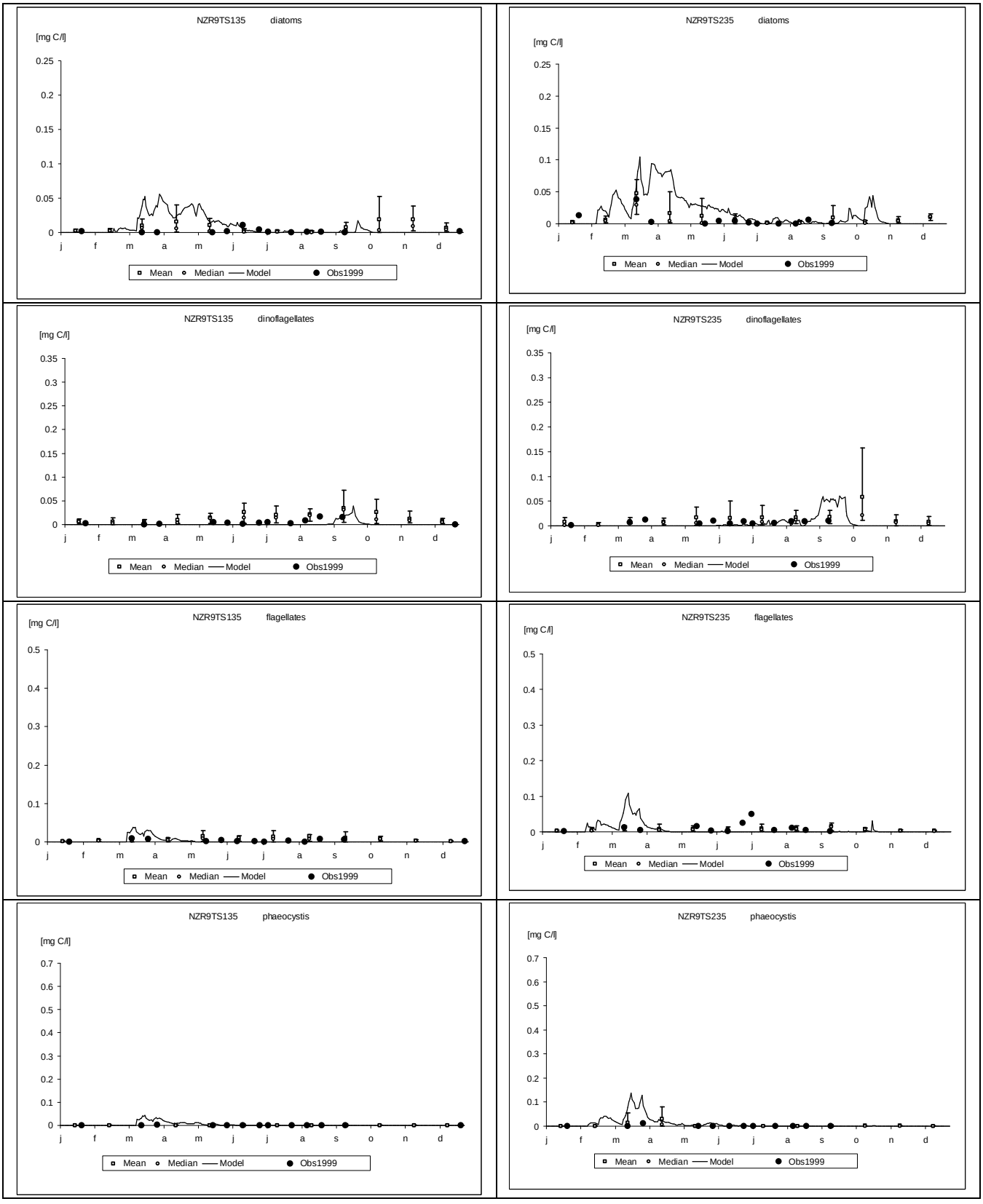


Figure 2.10. Trends for data and a 3D-simulation of three species groups and one species in 2000 at Terschelling 135 and Terschelling 235.

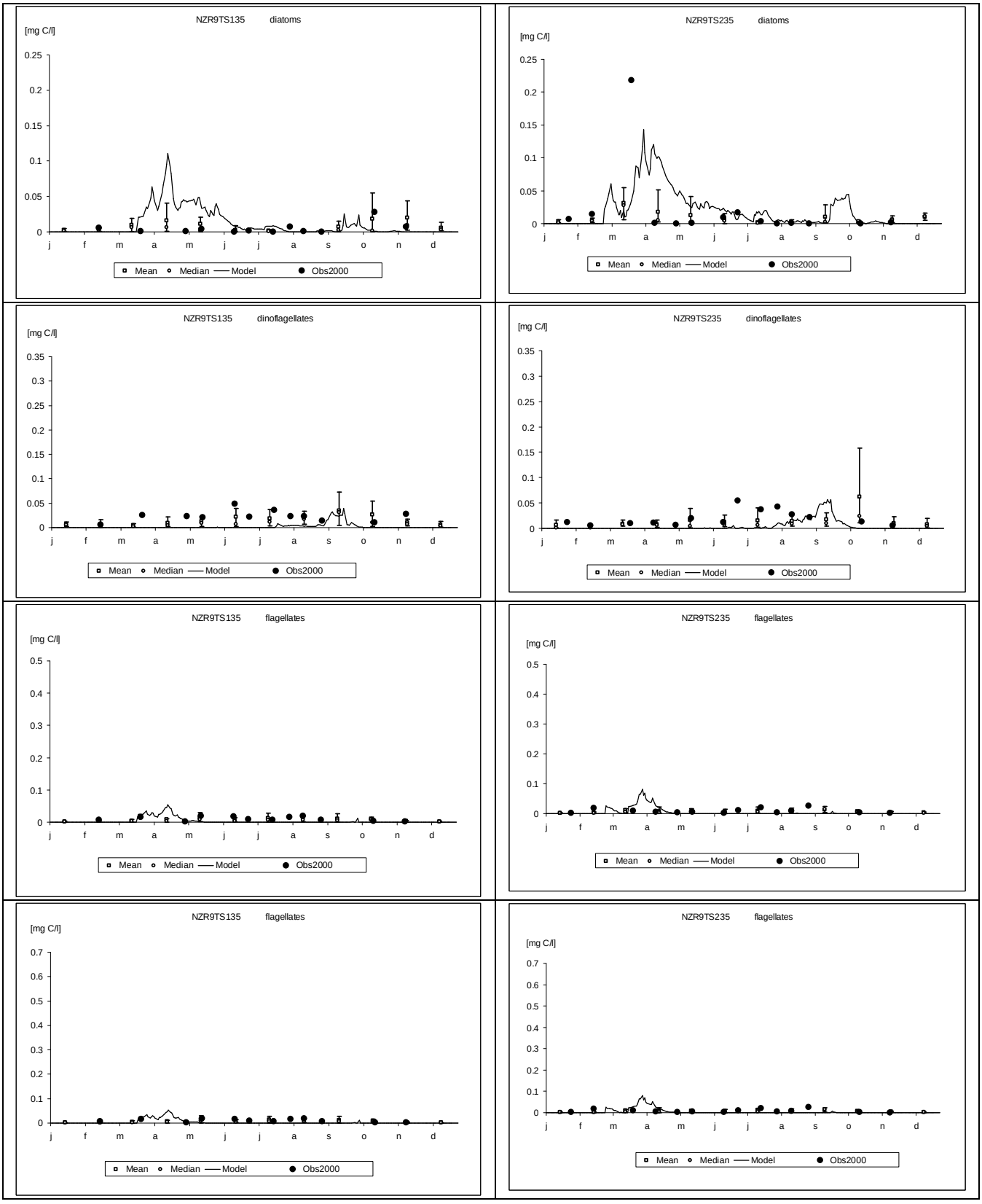


Figure A 2.11. Trends for data and a 3D-simulation of three species groups and one species in 2001 at Terschelling 135 and Terschelling 235.

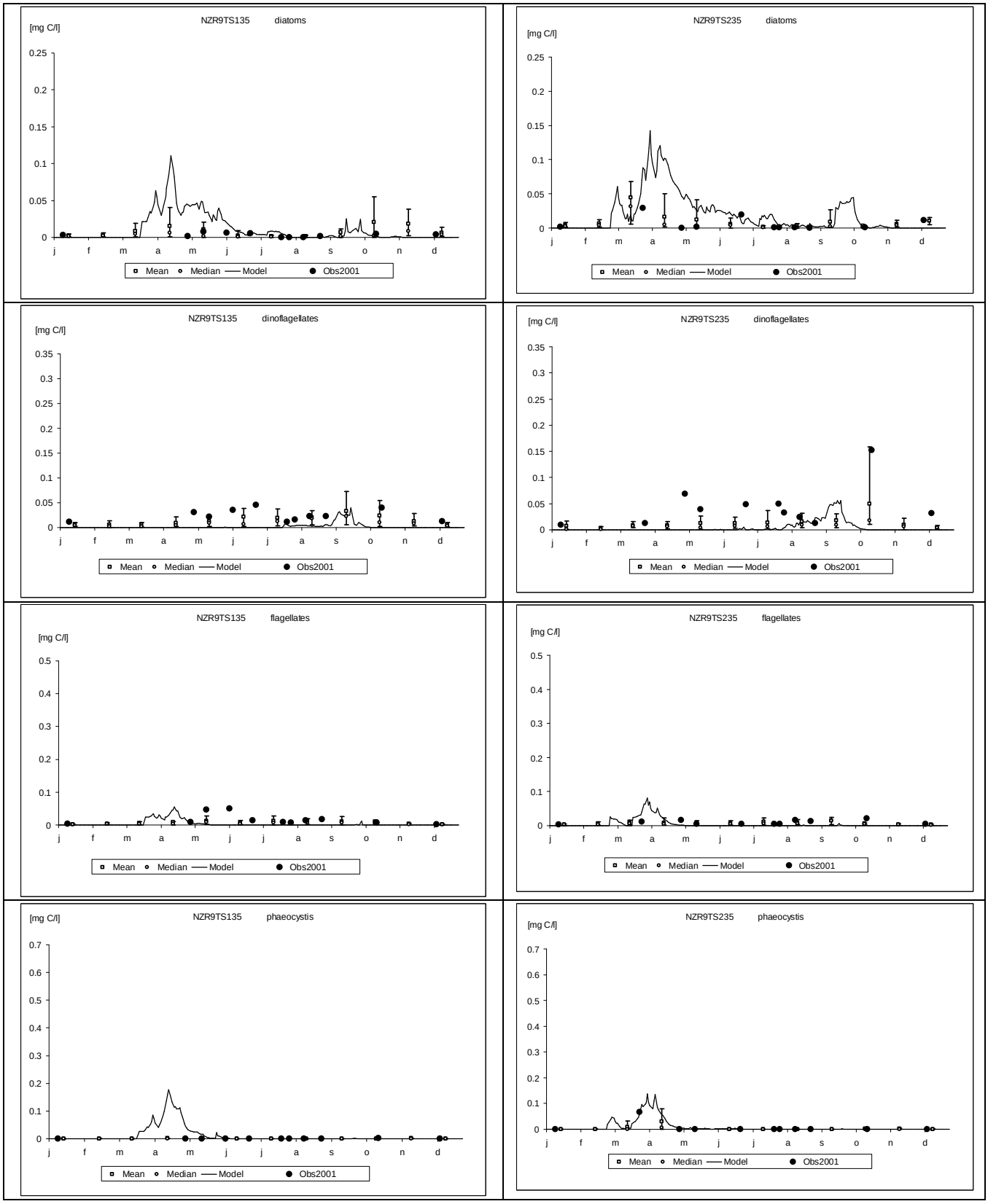


Figure A 2.12. Trends for data and a 3D-simulation of three species groups and one species in 2002 at Terschelling 135 and Terschelling 235.

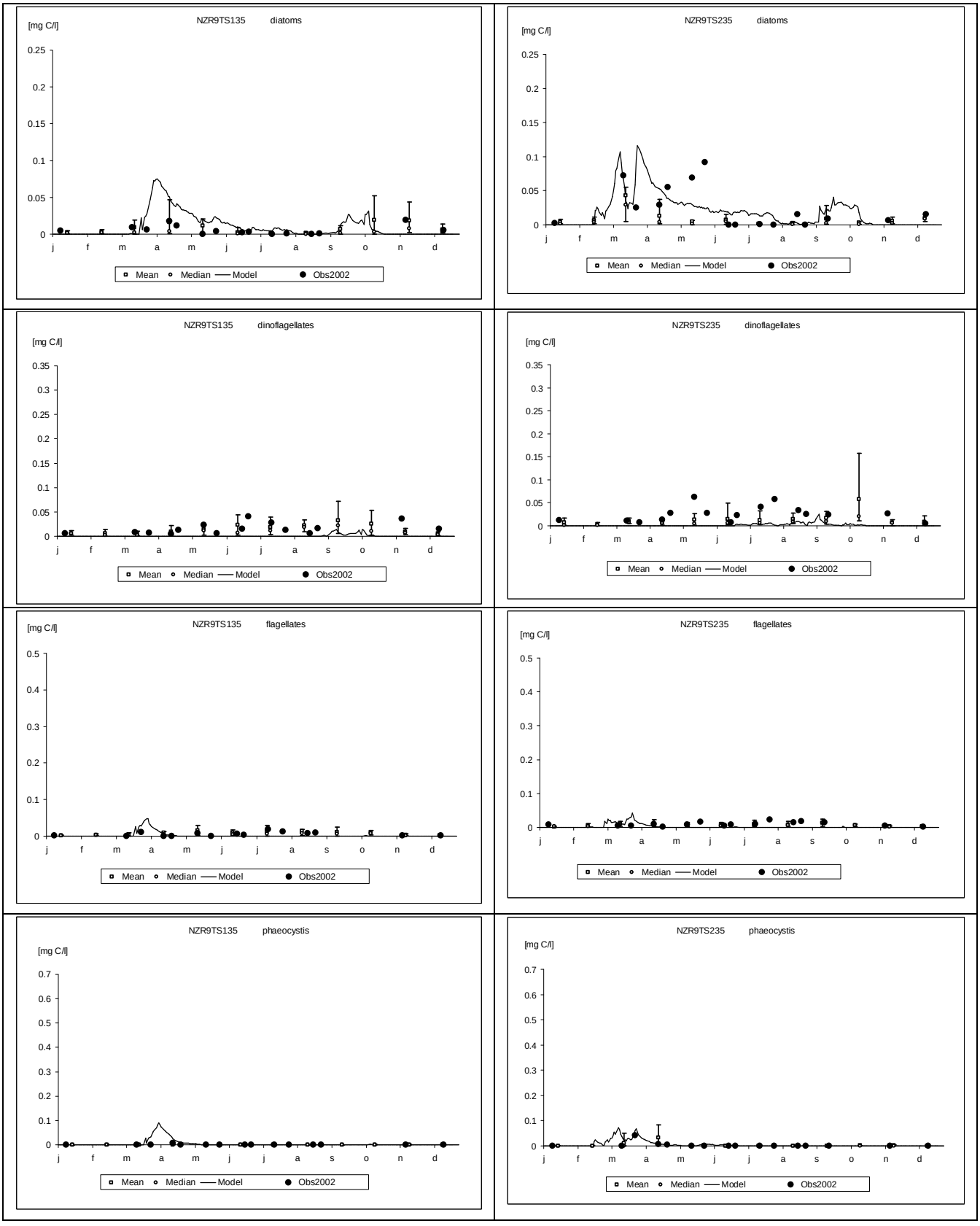


Figure A 2.13. Trends for data and a 3D-simulation of three species groups and one species in 2003 at Terschelling 135 and Terschelling 235.

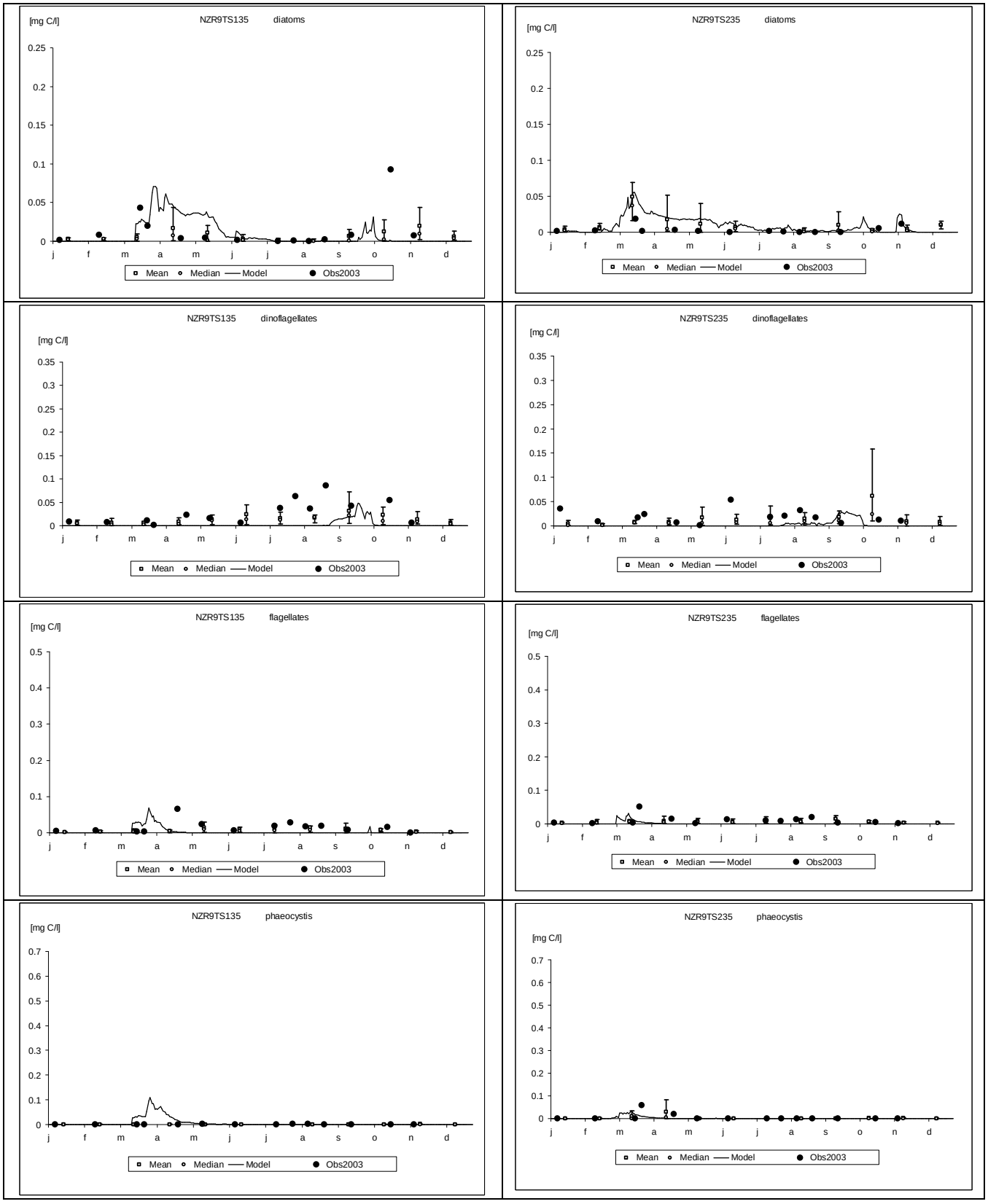


Figure A 3.1. Trends for data and a simulations of chlorophyl concentrations at the stations Noordwijk 10 and Noordwijk 70 for the years 1991-1994

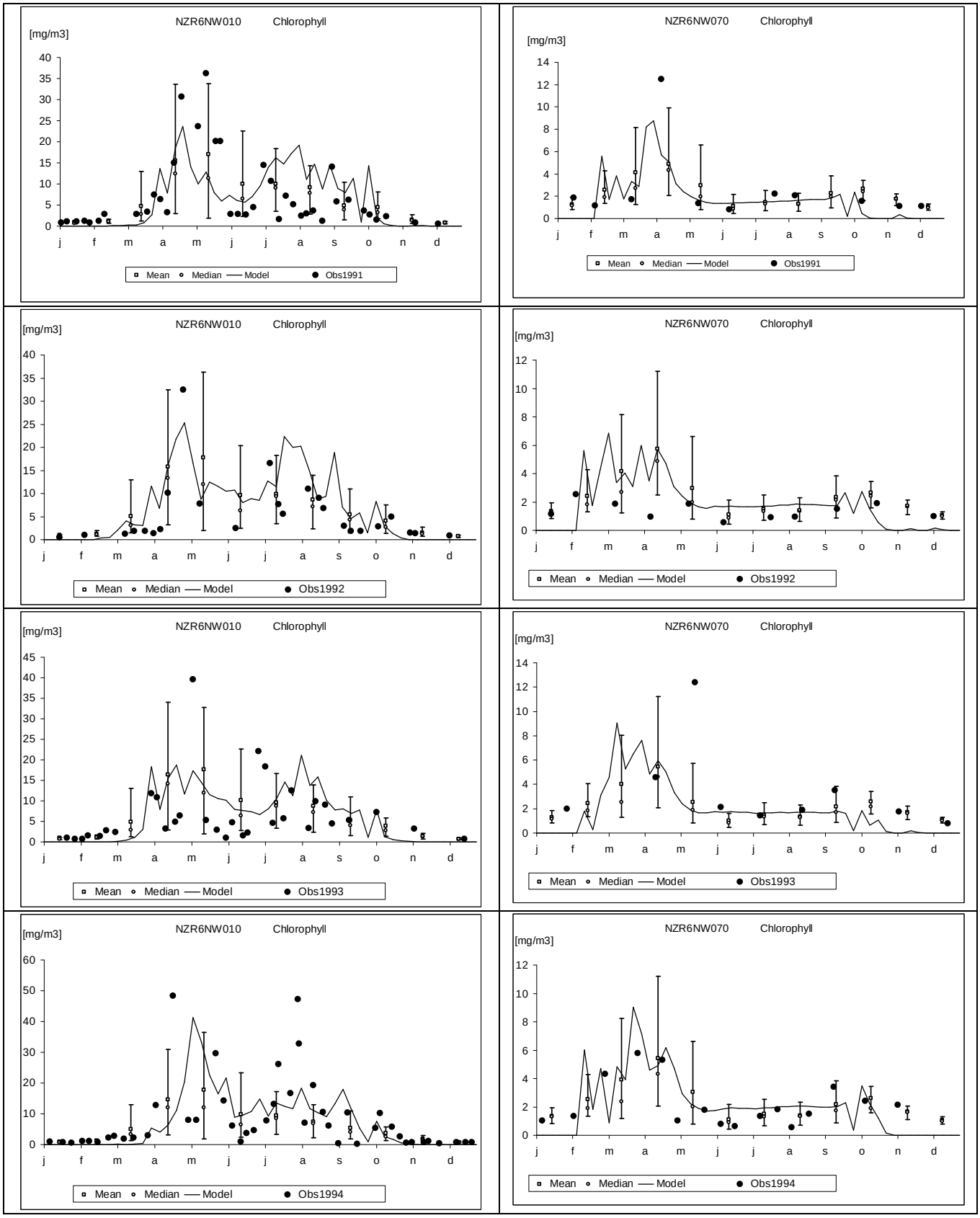


Figure A 3.2. Trends for data and a simulations of chlorophyl concentrations at the stations Noordwijk 10 and Noordwijk 70 for the years 1995-1998

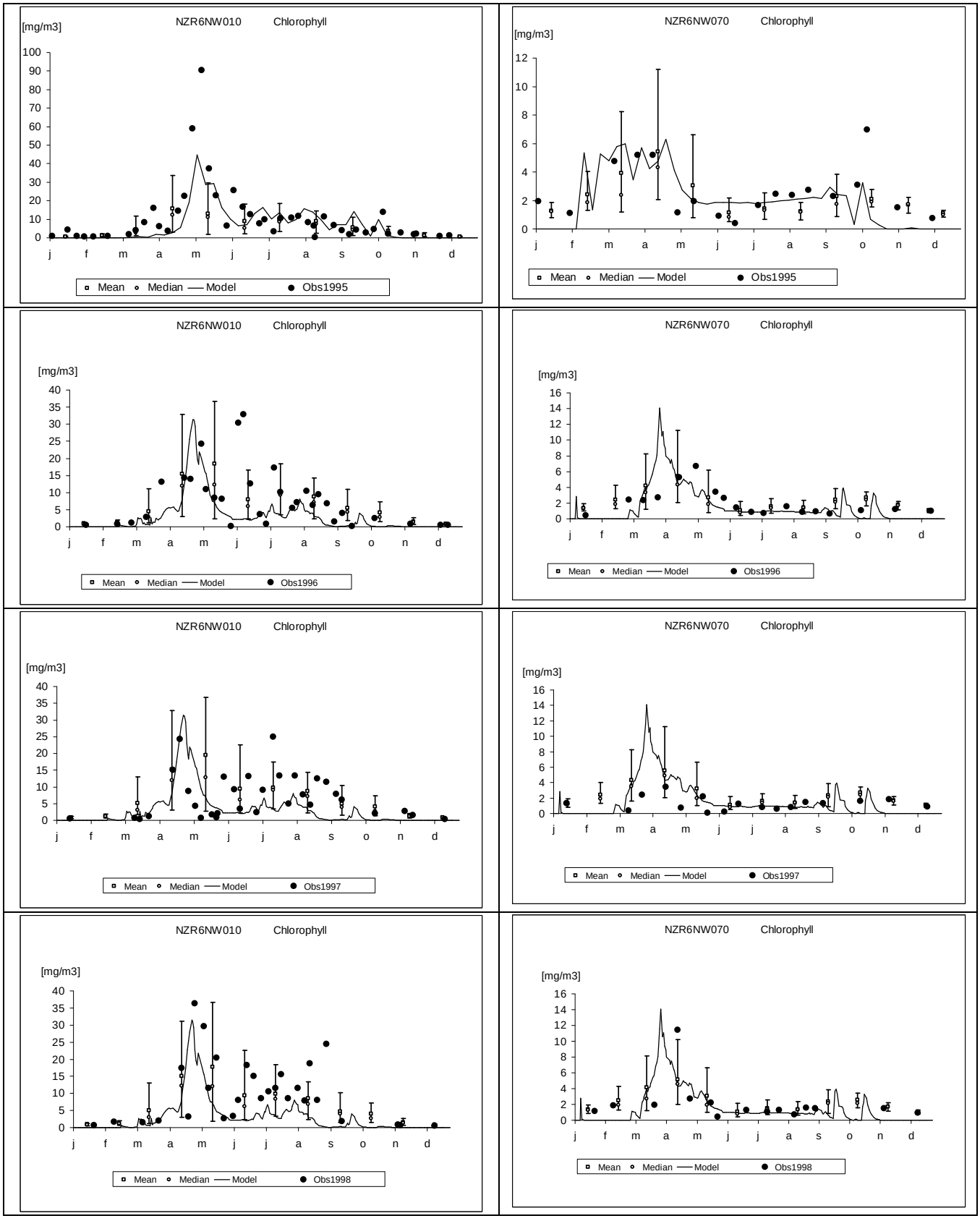


Figure A 3.3. Trends for data and a simulations of chlorophyl concentrations at the stations Noordwijk 10 and Noordwijk 70 for the years 1999-2002

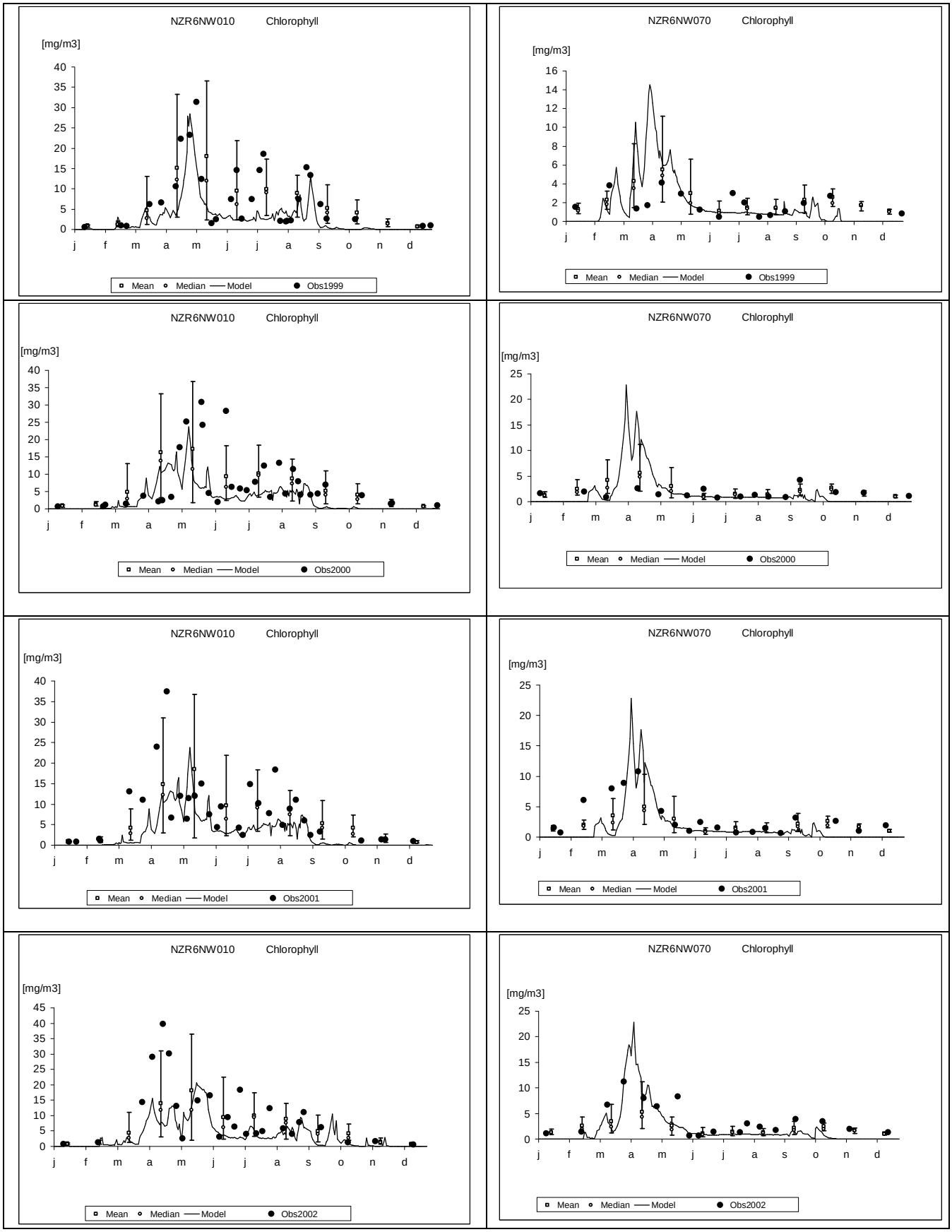
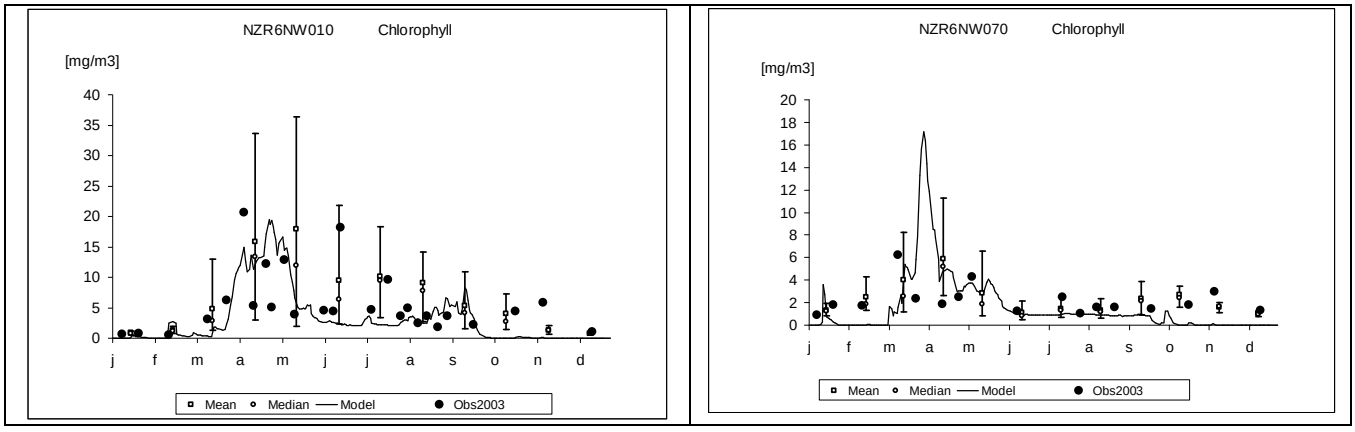


Figure A 3.4. Trends for data and a simulations of chlorophyl concentrations at the stations Noordwijk 10 and Noordwijk 70 for the year 2003



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