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ORIGINAL ARTICLE

Karen H. Wiltshire · Claus-Dieter Dürselen

Revision and quality analyses of the Helgoland Reede long-term phytoplankton data archive

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Abstract The Biological Station on Helgoland has one of the longest data series for phytoplankton species composition in the world. Since 1962, phytoplankton has been counted to a species level on a daily basis (weekdays). One of the main reasons why this data set has rarely been used is that it has never been subjected to proper quality control or inventoried properly. This paper describes the quality control which we have now carried out on this data set and also represents the first inventory of the data and its meta-information. A comparison of the electronic database where the data is archived and the original recorded lists from the different persons dealing with the samples was an integral part of the evaluation. Apart from recording inconsistencies in species identification, we also recorded and corrected the many differences found between the electronic and paper data. The evaluation was carried out in a direct comparative manner to discern taxonomic discrepancies, and in order to find random errors in the transfer of data from paper to computer random checks of the data were carried out. This paper serves to illustrate the level of quality control required when dealing with archived phytoplankton data and illustrates the typical problems encountered.

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K. H. Wiltshire (✉)
Alfred-Wegener-Institut für Polar- und Meeresforschung,
Biologische Anstalt Helgoland, Kurpromenade,
27498 Helgoland, Germany
E-mail: kwiltshire@awi-bremerhaven.de
Tel.: +49-4725-819238
Fax: +49-4725-819283

C.-D. Dürselen
AquaEcology, Marie-Curie-Strasse 1,
26129 Oldenburg, Germany

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Introduction

Long-term monitoring of biological, chemical and physical parameters has been carried out continuously at Helgoland Reede on a daily basis (workdays) since 1962 (e.g. Hagmeier 1978; Radach and Berg 1986; Gillbricht 1988; Radach and Bohle-Carbonell 1988; Hickel et al. 1992, 1993, 1994). Thus, the Helgoland long-term series is one of the longest aquatic data sets in history. What makes it unique are the phytoplankton species numbers which have been counted 5 days a week in this time period. The methods used did not vary over time. Surface water samples were taken (usually before 9 a.m.) on workdays at the "Kabeltonne" site (54°11.3′N, 7°54.0′E) between the two islands at Helgoland using a bucket. This sample was mixed well and subsampled into a glass bottle for future analyses of nutrients and phytoplankton. The phytoplankton samples taken from this were preserved in brown glass bottles using Lugols solution. Using the Utermöhl method (25 ml settled out), the samples were counted daily to species level under an inverted microscope. The time-series is often cited and taken for the discussion of changes evinced in the North Sea pelagic system over recent decades. It is also regularly a fixed item in lectures on marine ecology and is very important for the parameterisation and validation of mathematical ecosystem models. This data set, in its electronic form, is becoming increasingly more valuable within the framework of biodiversity and global change considerations (Wiltshire and Manley 2004). However, as it had never been validated or subjected to rigorous quality control, its reliability was questionable. It was our aim to evaluate the data set for its usability and to document its contents and correct it where errors were found. This paper describes the outcome of this procedure and documents the meta-information required to understand the data set.

Methods and results

Data inspection and stock-taking

The first step which had to be taken in order to understand which data were available was the collection of all the relevant data in one easily manageable archive. Thus, all electronically archived Helgoland Reede data since 1962 available in different formats (www.pangaea.de) were combined in an MS Access database. This provided the uniform structure needed for comparative purposes. The data included the meteorological, physical, chemical and biological data. The latter contained abundance and biomass data for phytoplankton down to a species level. The other data was used here as meta-information. Once the data were accessible, we set about modernising the taxonomical nomenclature, whereby the conversions from out-dated names and synonyms were also carefully documented in the names list. Then the evaluation of the documented occurrence of 40 years of phytoplankton species could proceed.

Two different species "checklists" for planktonic organisms had been used over the last 40 years for the time-series species documentation (see Appendix). The older one (last updated in 1970) was divided into two groups of phytoplankton (diatoms and flagellates) and several groups of zooplankton (which are not shown here). For each species, genus or group, a size class and corresponding carbon content per cell was given. Up to ten size classes for a single species or genus were sometimes distinguished in this list. Some genera, like *Chaetoceros*, *Coscinodiscus* and *Thalassiosira*, were only present as different size classes and no species names were documented. When comparing the 1970 checklist with the data on paper we found that it was used in an irregular manner. Species which appear in the electronic database for the early years are also found on the original data sheets, but not necessarily on the checklist. Examples are: *Chaetoceros decipiens* Cleve; *Coscinodiscus concinnus* W. Smith; *Dactyliosolen fragilissimus* (Bergon) Hasle; *Thalassiosira nordenskioeldii* Cleve; *Dinophysis acuta* Ehrenberg; and some more.

The second checklist was used from around 1976 to 2001 and was last updated in 1991. In 2001 a new checklist was started and is presented in Hoppenrath (2004). In the second list, planktonic organisms are divided into five groups (centric diatoms, pennate diatoms, flagellates, protozoa and metazoa). It contains more organisms on a species level, fewer different size classes for single species and fewer indeterminable species (at the genus level) than the earlier list. A size, in μm, with one or two dimensions, and fixed carbon content per cell was assigned to each species, size class and group.

The two lists were compared to determine their congruencies. Together with the data on paper and the different electronic versions, a species inventory was built up. This resulted in two different groups of species data:

1. Species data, seemingly accurate, based on our knowledge, literature information and questioning of the original sampling and counting persons (who luckily are still contactable). Such species appear in both of the original lists and they seem to have been recognized and counted correctly; and
2. species where data had to be further checked before accepting them into the database.

Time charts of the abundances since 1962 were made for all species, size classes and groups found in the electronic database. All of these charts were carefully examined for inconsistencies, conspicuousness and possible mistakes in connection with the existing checklists, with the experience of the authors, and other results from phytoplankton investigations from the area around Helgoland since 1960. Figure 1 shows two of these charts as an example, and Table 1 provides some comments for a few species examples.

Four time periods with obviously different counting results were differentiated, mainly related to the different counters. These time periods were 1962–1975, 1976–1993, 1994–1997 and 1998–2001, whereby the last period resembles the first two periods in many respects, for example in using the same size classes for species or genera. From the available data it can be concluded that a significant change in organism recognition in connection with the checklists probably took place in 1976. There is an evident change in data composition in 1994, although the person dealing with the samples only changed in 1995.

During quality control we found that a number of species which are regularly found in the German Bight (Hoppenrath 2004) never appeared in the Helgoland Reede data archives, e.g. *Chaetoceros eibenii* Grunow, *Chaetoceros diadema* (Ehrenberg) Gran, *Chaetoceros danicus* Cleve, *Protoperidinium curtipes* (Jørgensen) Balech.

A serious anomaly found in the data was related to the fact that in the electronic data archive more species were found than had originally been recorded on paper and in the checklists. It seemed that undocumented retrospect changes had been made and previously unnamed species renamed by assigning specific size classes with speculative names. A conspicuous example of this problem was the alga *Coscinodiscus wailesii* Gran and Angst. The electronic database had the occurrence of *Coscinodiscus wailesii* archived from the early 1970s onwards. However, this was really only recorded in the German Bight in the late 1970s (Der Helgoländer 1977). Indeed, this species probably reached French waters via the introduction of Indopacific oyster cultures in the 1970s (Rincé and Plaumier 1986). From then on it spread slowly into the North Sea and appeared in very high numbers in the German Bight at the beginning of

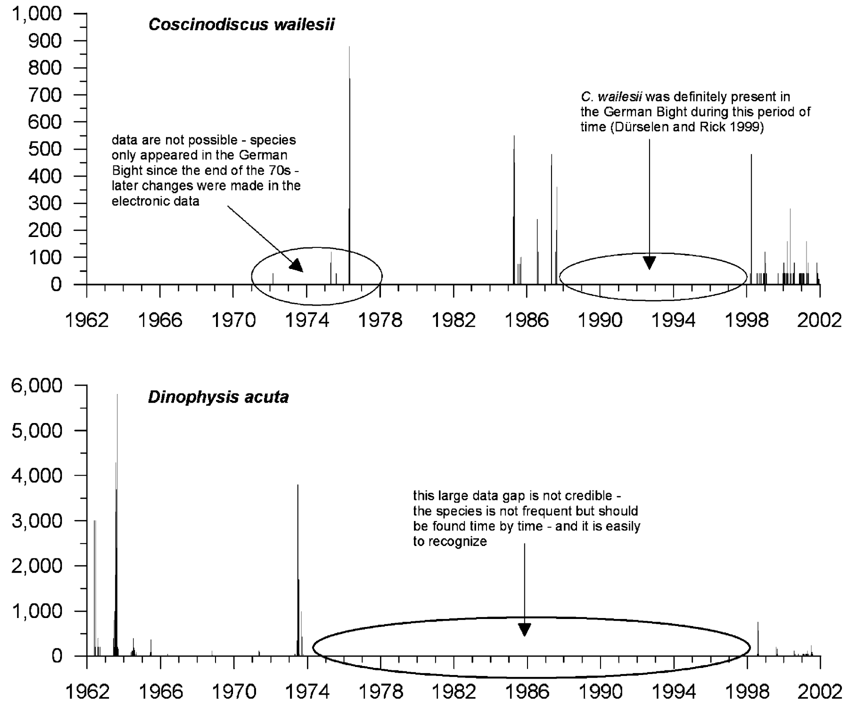


Fig. 1 Time charts of *Coscinodiscus wailesii* and *Dinophysis acuta* from the original Helgoland Reede data with comments from after the inspection

Table 1 Some examples of comments resulting from the inspection of the electronic Helgoland Reede phytoplankton data

Species	Conflicts	Details
Actinoptychus senarius (Ehrenberg) Ehrenberg	Data 1962–1993: one size classdata 1994–1997: not present/counteddata 1998–2001: one size classchecklist 1970: present in three size classeschecklist 1991: present in one size class	Between 1976 and 1997 no data are available. That cannot be! The species is not frequent, but it should always be present at low levels and it is also easy to recognize. Because the species ap peared in the checklist from 1970 with three size classes, but in the electronic database with only one, probably changes were made later (building of sums). This could become a problem when calculating carbon biomass.
Cerataulina pelagica (Cleve) Hendy	Data 1962–1993: two size classesdata 1994–1997: two size classesdata 1998–2001: two size classeschecklist 1970: present in two size classeschecklist 1991: present in two size classes	Usable! The seasonal occurrence of the species in the data is alright.
Coscinodiscus wailesii Gran and Angst	Data 1962–1993: two size classesdata 1994–1997: not present/counteddata 1998–2001: two size classeschecklist 1970: species not presentchecklist 1991: present in two size classes	The species only appeared for the first time at the end of the 1970s in European waters. Prior data are definitely wrong in the database! Later changes must have been made. Supposition: size classes with diameter 270 µm and/or 320 µm were changed to *C. wailesii*. However, this coincided with supposed changes from *C. concinnus*. The data gap between 1988 and 1997 does not reflect the actual distribution. During that time, the species was nearly always present and sometimes very frequent (Dürselen and Rick 1999). Although the recording of this very large species is statistically very difficult in small water volumes, it should have appeared now and then.
Leptocylindrus danicus Cleve	Data 1962–1993: one size classdata 1994–1997: two size classesdata 1998–2001: one size classchecklist 1970: present in three size classeschecklist 1991: present in one size class	This species is not always present, but the large data gaps (e.g. from 1974 to 1989) are not credible. On superficial inspection, confusion with small *Guinardia delicatula* is possible. The species can also build massive blooms, as reflected twice in the data. Because the species appeared in the checklist from 1970 with three size classes, but in the electronic database with only one, probably changes were made later (building of sums). This could become a problem when calculating carbon biomass.
Dinophysis acuminata Claparède and Lachmann	Data 1962–1993: one size classdata 1994–1997: not present/counteddata 1998–2001: one size classchecklist 1970: not presentchecklist 1991: present in one size class	Data gap between 1975 and 1997! The species should be found nearly every year. The species did not appear in the checklist from 1970. But then, where are the electronic data from? Possibly later changes were made. Supposition: size classes 30–45 µm and/or 40–50 µm were changed to *Dinophysis acuminata*.

the 1980s (Der Helgoländer 1984; Dürselen and Rick 1999). This data versus reality anomaly raised the question of where the data came from within the Helgoland Reede data set for *Coscinodiscus wailesii* in the time period before 1977. When we went back to the paper data it actually hadn't been recorded until the 1980s. Thus, the entries in the electronic data were considered erroneous. Because of this evidence that algae counted as indeterminate species in size classes at the genus level were later reclassified to a species, we then had to verify the occurrence of all the species entered in the electronic data with the original data sheets. Other examples of retrospect naming included most of the species from the genera *Chaetoceros*, *Coscinodiscus*, *Thalassiosira*, *Dinophysis*, *Gymnodinium*, *Gyrodinium* and *Protoperidinium*. Luckily, this retrospect renaming seemed to be the exception rather than the rule (see Table 2).

Because of the potential of this data set for examining plankton biodiversity against the backdrop of global change, one of the assessment criteria was the long-term credibility of the microalgal identification. Thus, those species were identified where the data are acceptable as a long-term series over the whole 40 years without any restriction or with some small restrictions. These are summarised in Table 3. Using this new information, species charts were made allowing easy comparisons of their long-term occurrence over the past 40 years (Fig. 2).

In addition to the above evaluations, randomised examination of the original lists revealed that some species from the original lists were included in the electronic database only as "sp." at the genus level (Table 4). It seems that it was difficult to electronically archive and change the list to accommodate new species. The structure of the original database program PLANKTI used (based on DOS) was relatively inflexible to change. Over and above these inconsistencies, others such as those documented in Table 5 were found during the evaluation of the original lists. We now hope we

Table 2 The most significant later changes which were found in the Helgoland Reede phytoplankton database compared with the original records

Species	Later changes
Coscinodiscus concinnus W. Smith	For this species, data in the electronic database were changed later—but not throughout. Sometimes the species was determined as *C. concinnus* in earlier years, sometimes it was counted as *Coscinodiscus* sp. size class 350 μm. And this size class was partly changed later to *C. concinnus*. Example: May 1985
Coscinodiscus wailesii Gran and Angst	For this species, data in the electronic database were changed later—but not from all size classes. Examples: March 1972*Coscinodiscus* sp. size class 400 μm was changed to *C. wailesii* later; May 1987 *Coscinodiscus* sp. size class 270 μm was changed to *C. wailesii* later
Coscinodiscus sp. Ehrenberg	When checking the electronic data with the original lists this genus was alright, except for some problems in classification of the size classes, which were not always the same over the years. This, however, only has any effect when calculating biovolume and biomass.
Dinophysis norvegica Claparède and Lachmann	This species was sometimes changed later from *Dinophysis* sp. as written down in the original lists. Example: May 1981
Gonyaulax spinifera (Claparède and Lachmann) Diesing	This species was changed later. In the original lists, only Gonyaulax sp. could be found. Example: June 1982
Gymnodinium mikimotoi Miyake and Kominami (*Gymnodinium aureolum* Hulburt)	This species was changed later. In the original lists, only *Gyrodinium* sp. could be found. Example: March 1987. The confusion between *Gymnodinium* and *Gyrodinium* led to another problem within this group which became evident later during the evaluation.
Pyrophacus horologicum Stein	This species was changed later. In the original lists, only *Pyrophacus* sp. could be found. Example: January 1975
Torodinium robustum Kofoid and Swezy	This species was changed later. In the original lists, only *Torodinium* sp. could be found. Example: June 1972

Table 3 Species and genera from the Helgoland Reede sampling whose data have been classified as usable after inspection

Species whose data are usable without restriction	*Thalassionema nitzschioides* (Grunow) Grunow, *Cerataulina pelagica* (Cleve) Hendey, *Eucampia zodiacus* Ehrenberg, *Guinardia delicatula* (Cleve) Hasle, *Guinardia flaccida* (Castracane) H. Peragallo, *Guinardia striata* (Stolterfoth) Hasle, *Odontella aurita* (Lyngbye) C. A. Agardh, *Odontella sinensis* (Greville) Grunow, *Paralia sulcata* (Ehrenberg) Cleve, *Rhizosolenia imbricata* Brightwell,*Rhizosolenia setigera* Brightwell, *Skeletonema costatum* (Greville) Cleve, *Ceratium furca* (Ehrenberg) Claparède and Lachmann, *Ceratium fusus* (Ehrenberg) Dujardin, *Ceratium horridum* (Cleve) Gran, *Ceratium tripos* (O. F. Müller) Nitzsch, *Noctiluca scintillans* (Macartney) Kofoid and Swezy, *Prorocentrum micans* Ehrenberg
Species whose data are usable with restrictions	*Pseudo-nitzschia seriata* (Cleve) H. Peragallo, *Detonula pumila* (Castracane) Gran, *Ditylum brightwellii* (West) Grunow, *Leptocylindrus minimus* Gran,*Odontella regia* (Schultze) Simonsen
Genera whose data are usable as a sum	*Chaetoceros* Ehrenberg, *Thalassiosira* Cleve, *Dinophysis* Ehrenberg, *Protoperidinium* Bergh

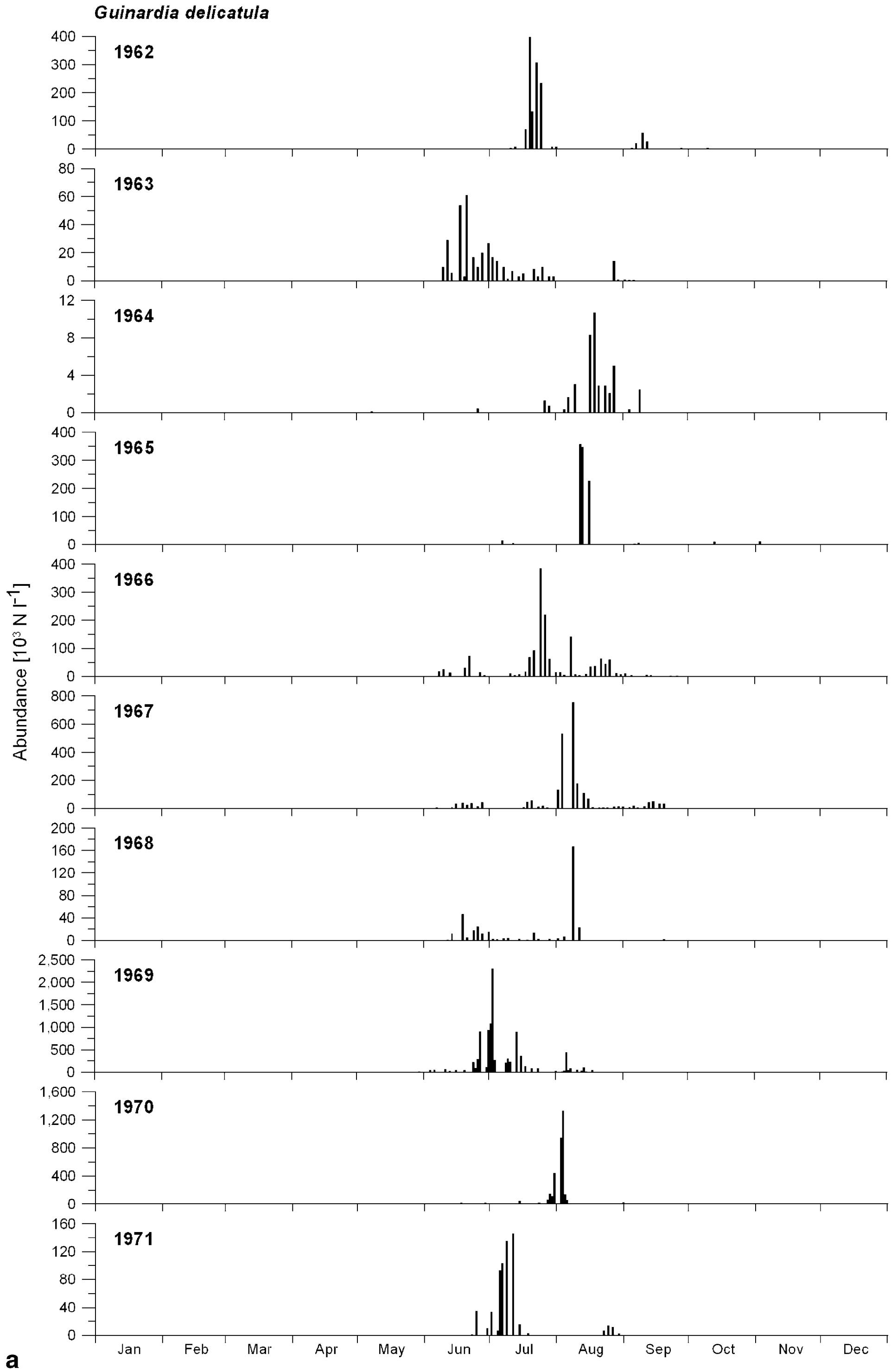


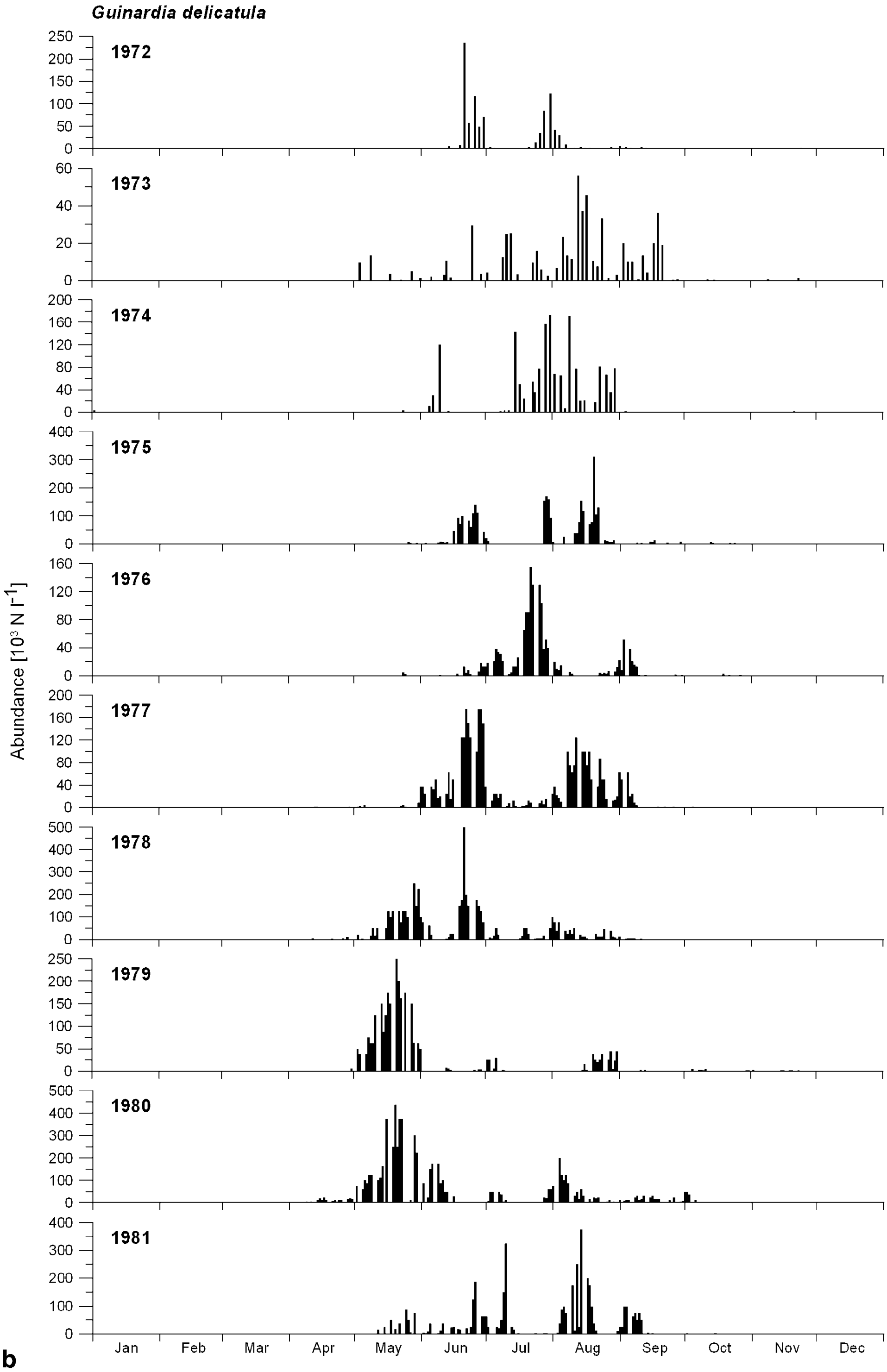
Fig. 2 *Guinardia delicatula* (Cleve) Hasle as an excellent example of meaningful abundance data from a long-term series

have recorded most of these anomalies, but with a database of this size (around 8,800 entries) we are sure to have missed some errors.

Changes in the electronic database

After having checked the data, it was decided to make some changes in the electronic database, returning the data to a copy of the original recordings on the data sheets. However, this in itself proved to be a difficult procedure. First, some species were deleted from the electronic database, because no data had been entered for them. Unfortunately this also included the algae *Thalassiosira anguste-lineata* and *Thalassiosira eccentrica* which, although they intermittently appear in the original data sheets (as already mentioned in Table 4), were never entered

Fig. 2 (Contd.)



into the database. Thus, in the electronic database the data from these species only appear as size classes from the genera. To change all this back to the original recordings would have meant the evaluation of the nearly 8,800 original lists: this is currently not a practical solution.

All records of *Coscinodiscus concinnus* and *Coscinodiscus wailesii* were checked and changed back correspondingly, if the species was only written down as *Coscinodiscus* sp. with a special size class in the original lists. During this procedure it was noticed that most of the entries for *Coscinodiscus* sp. in the different size classes from the original data sheets are not available in the electronic database. For the dates where *Coscinodiscus concinnus* and *Coscinodiscus wailesii* were checked and additional missing *Coscinodiscus* sp. entries were

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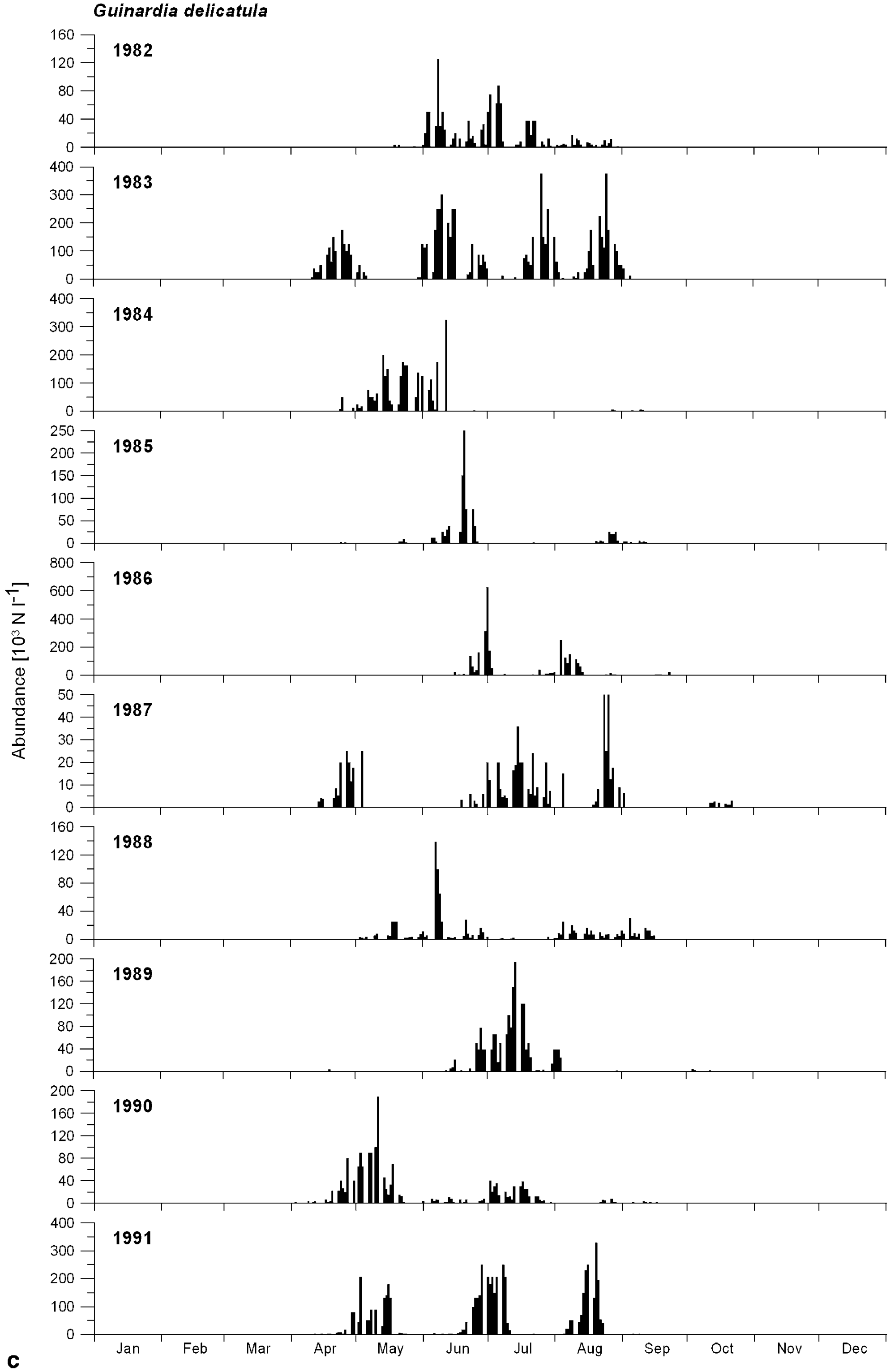
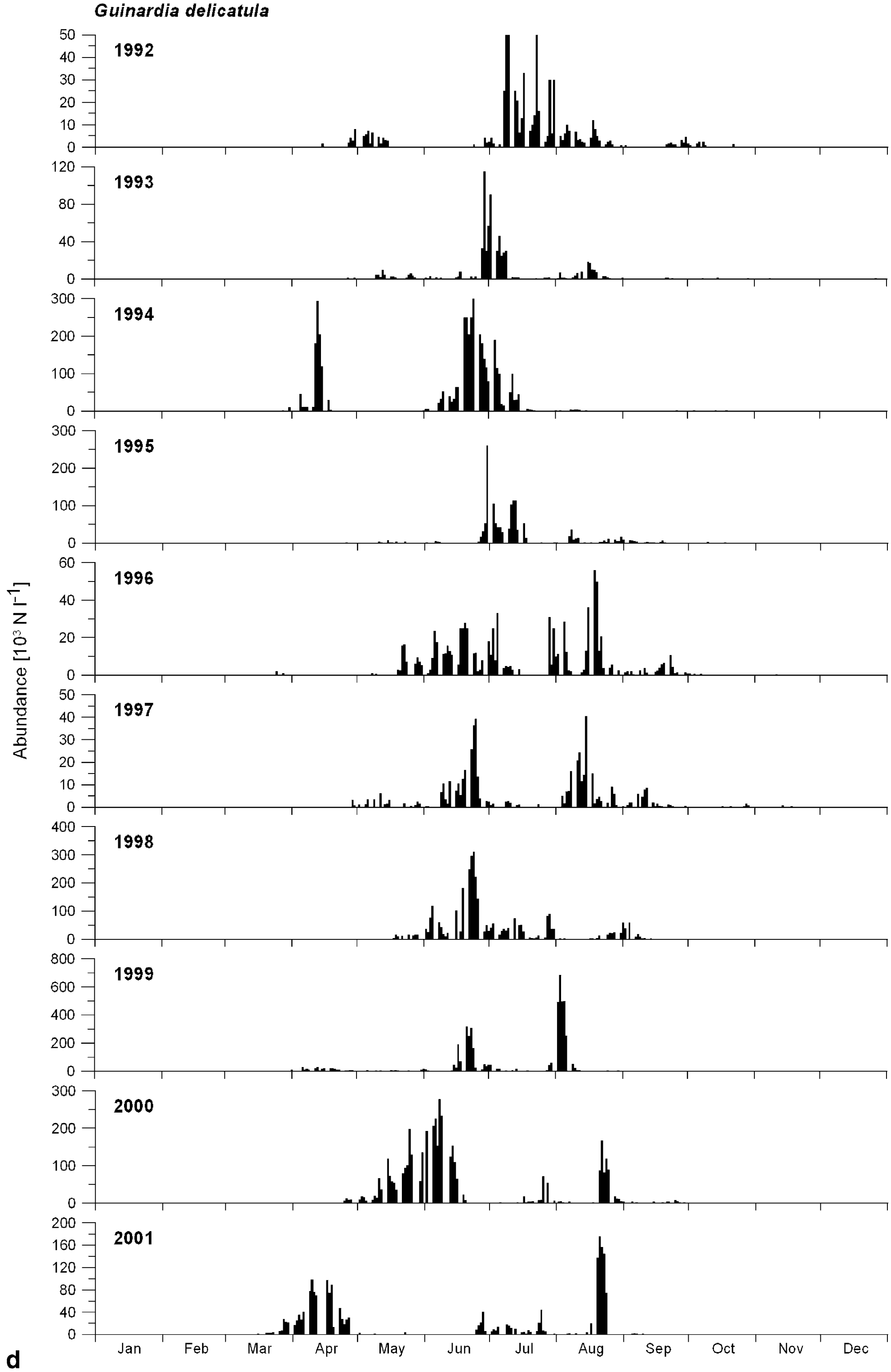


noticed, these data were added to the electronic database. As with the algae mentioned above, the original data sheets would have to be re-entered to ensure a perfect copy of the data.

Gonyaulax spinifera (Claparède and Lachmann) Diesing from the electronic database did not appear in the original lists. It was always written down as *Gonyaulax* sp.: therefore, it was changed back to this term in the electronic version. The same applied to *Pyrophacus horologicum* Stein.

Great data confusion was detected for *Gymnodinium* and *Gyrodinium*, which very often seemed to have been used as synonyms by the counters. One example from 1980 illustrates this dilemma: data for *Gymnodinium* sp.

Fig. 2 (Contd.)



size class 75 µm, from the original lists was found in the electronic version as *Gyrodinium* sp. size class 75 µm. On the other hand, *Gymnodinium* sp. size class 40 µm, was found as *Gymnodinium* sp. size class 50 µm. These data would also have to be re-entered to ensure absolute accuracy.

Carbon biomass

The evaluation of the phytoplankton archive would not be complete without dealing with the problem of carbon biomass calculated from cell size, as these data have been continuously cited and used in the literature (e.g.

Table 4 Species found during the spot check control of the original records which had been changed to the genus level in the electronic database

Species	Problem
Chaetoceros curvisetus Cleve	This species is not included in the database. Example: On 2 May 1973 it was written down in the original lists at the species level but found in the database as *Chaetoceros* sp.1 (size 10 μm). On 4 May 1966 it was written down in the original lists at the species level but found in the database as *Chaetoceros* sp.2 (size 20 μm)—with the same size class in the original lists as in 1973. The same can be found for other time periods.
Chaetoceros tortissimus Gran	This species is not included in the database. Example: On 28 April 1976 it is written down in the original lists at the species level.
Chaetoceros teres Cleve	This species is not included in the database. Example: On 4 May 1966 it is written down in the original lists at the species level.
Thalassiosira anguste-lineata (A. Schmidt) G. Fryxell and Hasle [*Thalassiosira polycorda* (Gran) Jørgensen]	This name was found in the database, but without any data. Example: On 3 May 1972 it is written down in the original lists at the species level but found in the database as *Thalassiosira* sp.4 (size 45 μm) although there was a field for data from *T. anguste-lineata*.
Thalassiosira eccentrica (Ehrenberg) Cleve	This name was found in the database, but without any data. Example: On 3 May 1972 it is written down in the original lists at the species level but found in the database as *Thalassiosira* sp.3 (size 30 μm) although there was a field for data from *T. eccentrica*.
Thalassiosira rotula Meunier and *Thalssiosira nordenskiöldii* Cleve	Both species were found in the original lists on e.g. 12 April 1991. But the data appeared in the database as *Thalassiosira* sp. although both species names were included in the database.
Melosira nummuloides C.A. Agardh	This species was changed to *Melosira* sp. in the database on e.g. 21 March 1975.

Table 5 More inconsistencies between the electronic database and the original lists

Species	Inconsistency
Asterionellopsis glacialis (Castracane) Round	Example from 5 August 1976: this species was counted both within the whole sedimentation chamber and with several visual fields. The calculation for the abundance per litre led to two different results: 35,000 cells l^{-1} and 20,000 cells l^{-1}. Only the first result was taken up into the database.
Chaetoceros socialis Lauder	For this species, only colonies were counted. This could be a problem for the estimation of carbon biomass.
Protoperidinium sp. Bergh	Example from 12 June 1968: in the original list there is a *Protoperidinium* sp. without giving a size class, which appears in the database as *Protoperidinium* sp.3 or *Protoperidinium* sp.4. Two other *Protoperidinium* in the database (*Protoperidinium* sp.3 or sp.4 and *Protoperidinium* sp.6) could not be found in the original list.
Biddulphiales indeterminable	Example: on 15 August 1973 in the original list, only 'Diatom' is written for one of the counted organisms. There is no information that it is a Biddulphiales. But the data appear in the electronic database as indeterminable Biddulphiales.
Bacillariales indeterminable	Example: on 28 March 1973 in the original list, only 'Diatom' is written for one of the counted organisms. There is no information that it is a Bacillariales. But the data appear in the electronic database as indeterminable Bacillariales. In addition, two size classes were combined.
	Examples May and August 1970: Only five–six species were written down in the original lists each day. It is unlikely, at that time of year, not to find more species.
Gymnodinium sp.4	There is a typing error in the database on 27 May 1987: it reads 240 instead of 160.

Eppley et al. 1970; Strickland and Parsons 1972; Verity et al. 1992).

Estimations of cell sizes had been made since 1962 by nearly all of the different counting individuals and were written down in the original data lists. However, these data were unfortunately not taken into the electronic database. Instead, fixed carbon contents (see checklists in the Appendix) were assigned to each species for the 40 years of sampling. This is unfortunate, as algal size varies considerably and, consequently, carbon relationships vary as well. In particular, diatoms are highly variable in their size and proportions, causing a factor of two or even three in the biovolume of the same species at different time periods. Thus, to achieve a proper estimation of biomass and carbon for each sample, the dimensions of the actual organisms should have been used, rather than the fixed values. With the original data, a more effective estimation of the carbon biomass would be possible and this should, if possible, be rectified in the future.

Discussion

The quality control of the data was imperative as there is an immense pressure on the release of the species data for evaluation of the time-series regarding long-term changes in the North Sea. In particular, the flagellate data needed to be evaluated as it has often been used to show an increase of algal biomass in the German Bight. This can be summed up as follows:

The evaluation of the Helgoland Reede data has shown a significant increase in the phytoplankton biomass since 1962. Hagmeier (1978) already presented an annual mean increase of biomass from 1962 until 1974 of from 25 μg C l^{-1} to more than 50 μg C l^{-1}. Gillbricht (1983) calculated a mean increase of up to 200 μg C l^{-1} during the vegetation period (April to September) between 1962 and 1981. Radach and Berg (1986) analysed the data up until 1984 using trend analysis, which also showed a significant increase in phytoplankton biomass (from 8.3 μg C l^{-1} to 34.8 μg C l^{-1}, including all the summer and winter data) with a mean exponential growth rate of 0.027 a^{-1} over 23 years. Greater phytoplankton biomass was especially found in water with lower salinity (increase of 10.5 μg C l^{-1} to 56.2 μg C l^{-1}). An increase was found for the summer data (from 28.2 μg C l^{-1} to 75.9 μg C l^{-1}) as well as for the winter data (from 1.8 μg C l^{-1} to 21.9 μg C l^{-1} in water with lower salinity and from 2.3 μg C l^{-1} to 15.5 μg C l^{-1} in water with higher salinity). Comparing the development of diatoms with that of flagellates, it is obvious that the increase is mainly due to a growth of flagellates, whose biomass was ten times higher in 1984 than in 1962 (25 μg C l^{-1} versus 2.5 μg C l^{-1}). The biomass of diatoms, in contrast, had not increased by 1986 (Radach and Berg 1986), and nor has it increased since (Hickel et al. 1992, 1994; Wiltshire and Manly 2004). Nevertheless, an extremely high biomass of flagellates has been observed in some years (Hickel et al. 1992).

The observed flagellate biomass increase at the end of the 1970s could possibly be due to the method of determination: the fixed samples taken during the first half of the time-series were stored for longer before being evaluated (Hickel et al. 1993). Meanwhile, it is known that many flagellates are destroyed by the act of fixation (e.g. Reid et al. 1990) and that successfully fixed organisms can fall apart after being stored for a longer period of time. Since the end of the 1970s, samples taken at Helgoland Reede have been evaluated within a few days. It is unlikely that this affected the diatom counts, however, as these have remained stable over the years (Wiltshire and Manly 2004). These storage effects on the flagellate numbers have been further compounded by the introduction of a new microscope in 1998. The result was a quantum leap in numbers of flagellates recognised. Consequently, these effects must always be kept in mind when considering these results.

Another aspect which has to be regarded when discussing the Helgoland Reede phytoplankton data is the frequent change in the counting persons (Fig. 3). Where possible, people always counted in parallel for a few months before the first person retired. However, the personal element involved in the recognition of microalgal species cannot be eliminated completely, and it is clear from the data that leaps in numbers often coincided with personnel changes. It is unfortunate that some of the phenomena particularly related to the flagellate numbers discussed in the literature, for example a concomitant increase in flagellates with an increase in nutrients in the German Bight, could also potentially be ascribed to a change in the counting person (Fig. 4).

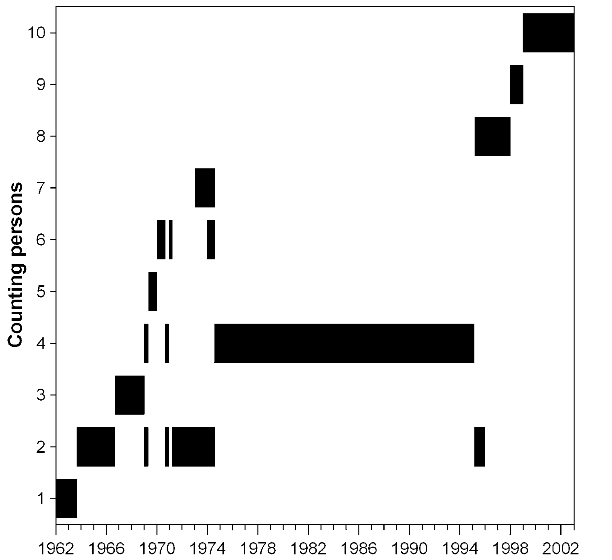


Fig. 3 Time periods in which ten different investigators counted the phytoplankton sample from Helgoland Reede

This naturally does not mean that all of the ideas are wrong. The variability and heterogeneity of the pelagic system in the German Bight is well known. Sometimes, unexpected phenomena appear. Without the control of the original water samples, many of the questions concerning the counting by different people cannot be reconstructed.

Especially for the dinoflagellates and other flagellates, it became evident during this check that there was a large difference in the taxonomic knowledge of the dif-

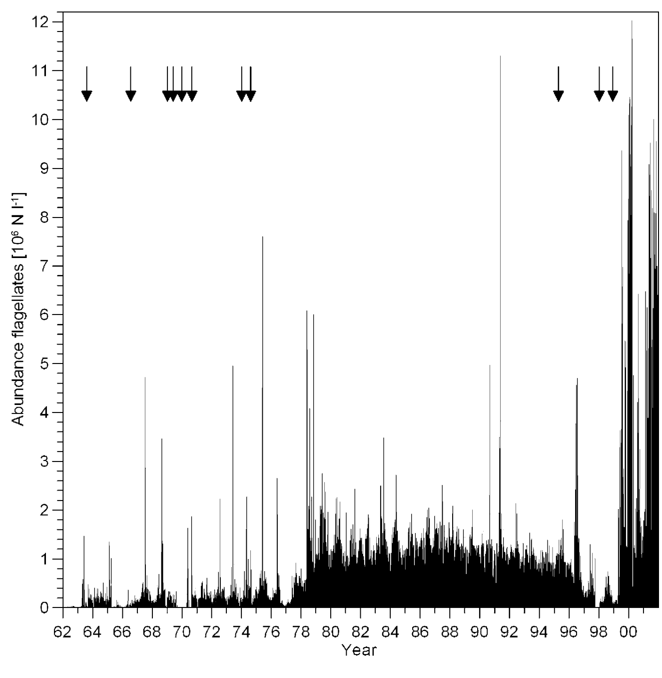


Fig. 4 Time chart of total flagellates. The *arrows* mark changes in investigator

Table 6 The earliest Helgoland Reede checklist (last update 1970)

Group	Genus	Species	Size (μm) [a]	Carbon (μg C indiv.$^{-1}$)
Diatoms	*Actinoptychus*	*undulatus*	22	0.0004
			40	0.0007
			52	0.0015
	Achnantes	sp.	18; 38	0.0002
	Asterionella	*japonica*	8	0.0002
	Bacillaria	*paradoxa*	4; 70	0.00007
	Bellerochia	sp.	30	0.0002
	Biddulphia	*aurita*	14; 40	0.0003
			17; 15	0.0005
			22; 33	0.0003
			25; 60	0.0006
			35; 35	0.0005
			40; 40	0.0006
			35; 50	0.0007
			45; 30	0.0006
		alternans	22	0.0001
			24	0.0001
			35	0.0003
		favus	34	0.0007
			110	0.008
		mobiliensis	50; 80	0.0025
			55; 90	0.003
			60; 60	0.002
			60; 100	0.0035
			70; 135	0.0055
			80; 90	0.005
			90; 100	0.007
			100; 125	0.01
		rhombus	110; 60	0.004
		sinensis	140; 120	0.01
			180; 290	0.05
			200; 220	0.03
	Cerataulina	*bergonii*	50; 70	0.002
			30	0.001
	Chaetoceros	sp.	6	0.000005
			14	0.00005
			17	0.00007
			22	0.00015
			30	0.0002
			40	0.0003
			50	0.0006
	Coscinodiscus	sp.	35	0.0005
			45	0.001
			55	0.0025
			60	0.003
			70	0.004
			80	0.005
			90	0.007
			210	0.08
			320	0.3
			270	0.2
	Ditylum	*brightwellii*	38; 120	0.003
			45; 150	0.005
			70; 230	0.013
	Eucampia	*zoodiacus*	30	0.0003
			60	0.0005
	Fragillaria	sp.	4; 8	0.00001
			6; 10	0.00002
			8; 12	0.00004
			8; 16	0.00005
	Grammatophora	*serpentina*	12; 18	0.0001
		marina	22; 40	0.0004
	Guinardia	*flaccida*	50; 70	0.0025
			60; 90	0.004
			70; 90	0.006

Table 6 (Contd.)

Group	Genus	Species	Size (μm) [a]	Carbon (μg C indiv.$^{-1}$)
	Gyrosigma	sp.	12; 55	0.00015
			14; 70	0.0002
			22; 80	0.0005
			25; 120	0.0009
			35; 170	0.002
	Hyalodiscus	*stelliger*	35	0.0005
			50	0.0015
			80	0.006
	Lauderia	*borealis*	26	0.0004
			30; 40	0.0007
			35	0.001
			40	0.001
	Leptocylindrus	*danicus*	4; 30	0.00003
			6; 40	0.00006
			9; 45	0.0001
		minimus	3; 40	0.00001
	Lithodesmium	*undulatum*	45; 80	0.0016
	Lycmophora	sp.	10; 25	0.00006
			11; 38	0.0001
			18; 48	0.0004
	Melosira (Paralia)	*sulcata*	8	0.00007
			12	0.0001
			16	0.0002
			20	0.0003
			25	0.0004
		nummuloides	12	0.0002
	Navicula	sp.	6; 30	0.00004
			8; 40	0.0001
			10; 60	0.00025
			12; 35	0.0001
			14; 60	0.0003
			16; 80	0.0008
			22; 38	0.0003
			26; 48	0.0005
			28; 80	0.0015
	Nitzschia	*closterium*	6; 110	0.00002
		delicatissimus	1; 40	0.000003
			3; 40	0.00001
		seriata	5; 70	0.00005
			5; 120	0.0001
	Rhizosolenia	*delicatula*	6; 60	0.00015
			9; 25	0.0001
			12; 45	0.0002
			20; 45	0.0004
			25; 40	0.0005
		setigera	3; 240	0.0001
			4; 150	0.00015
			6; 300	0.0005
			8; 220	0.0005
			12; 300	0.001
			15; 300	0.0015
			22; 300	0.0025
			26; 250	0.003
			28; 440	0.008
			40; 600	0.02
		shrubsolei	8; 150	0.0003
			10; 230	0.0007
			14; 200	0.001
			18; 270	0.0017
		stolterfothii	17; 50	0.0004
			20	0.00055
			25	0.0007
			35	0.001
	Skeletonema	*costatum*	5	0.00001
			12	0.00003

Table 6 (Contd.)

Group	Genus	Species	Size (μm) [a]	Carbon (μg C indiv.$^{-1}$)
	Schroederella	*schroederi*	20	0.00015
			30	0.0005
	Stephanopyxis	*turris*	28; 45	0.0007
	Streptotheca	*thamensis*	70; 100	0.002
	Thalassionema (Thalassiothrix)	*nitzschioides*	4; 48	0.00005
			8; 45	0.0002
	Thalassiosira	sp.	12	0.00005
			20	0.0002
			25	0.0003
			30	0.0005
			45	0.001
	Plagiogramma	*brockmanni*	20; 4	0.00002
Flagellates	Small flagellates		4; 8	0.00001
			6; 10	0.0002
	Large flagellates		10; 15–20	0.00005
	Coccolithophorids		5–6	0.000005
			10	0.00001
15	0.00005			
20	0.0002			
Silicoflagellates		25	0.0001	
		15	0.0001	
Dinoflagellates	Indeterminable	20	0.0003	
		30	0.0008	
		50	0.002	
		70	0.005	
Dinoflagellate cysts		80	0.01	
Amphidinuim	sp.	8; 12	0.00003	
		12; 15	0.00005	
Ceratium	*furca*	30–50	0.004	
	fusus	15–30	0.0025	
	horridum	30	0.003	
	lineatum	30	0.001	
	longipes	50	0.004	
	macroceros	50	0.004	
	tripos	75	0.01	
Dinophysis	sp.	20; 30	0.0002	
		30; 45	0.0005	
		40; 50	0.001	
Diplopsalopsis	sp.	45	0.0015	
		60	0.004	
Gyrodinium (Gymnodinium)	sp.	10; 35	0.0001	
		20; 50	0.0005	
		30; 70	0.001	
		50; 80	0.005	
		70; 90	0.007	
Noctiluca	*miliaris*	250	0.05	
		350	0.1	
		450	0.15	
		600	0.25	
Polykrikos	*schwarzii*	45; 80	0.004	
Prorocentrum	*micans*	30; 50	0.001	
		45; 70	0.002	
Pyrocystis	*lunula*	20; 120	0.001	
Peridinium	sp.	25	0.0005	
		35	0.01	
		45	0.002	
		60	0.005	
		80	0.01	
	depressum	150	0.02	
Phaeocystis (cells)	*globosa*	10	0.00002	
Phaeocystis (colonies)	*globosa*	Small 5,000	0.025	
		Medium 10,000	0.07	
		Large 15,000	0.2	

[a] In the size column normally the numbers indicate the diameter of the cells. If there are two numbers the second one is the length

Table 7 The second Helgoland Reede checklist (last update 1991). H heterotrophic

Group	Genus	Species	Size (μm) [a]	Carbon (pg C indiv.$^{-1}$)
Centric diatoms	*Actinoptychus*	*senarius*	60	2,000
	Bacteriastrum	*hyalinum*	40	1,500
	Bellerochea	*malleus*	70	800
	Centrales	Indeterminable	15	65
			30	300
			50	2,000
			70	4,000
			100	10,000
			150	25,000
			180	40,000
			200	70,000
	Cerataulina	*bergonii*	Small 30; 50	1,000
			Large 50; 70	3,000
	Chaetoceros	*debilis*	25; 20	150
		decipiens	Small 20; 20	100
			Large 40; 30	300
		densus	25	200
		didymus	20	110
		socialis	10	20
		sp.	10	20
			20	100
			30	200
			40	300
	Coscinodiscus	*concinnus*	Small 100	80,000
			Large 350	350,000
		granii	Small 100	10,000
			Large 250	15,000
		radiatus	80	4,000
		wailesii	Small 250	150,000
			Large 400	400,000
		sp.	200	70,000
			250	150,000
	Detonula	*confervacea*	10; 25	100
		pumila	30	300
	Ditylum	*brightwellii*	Small 40; 120	2,000
			Large 70; 150	5,000
	Eucampia	*zodiacus*	45	300
	Guinardia	*flaccida*	Small 50; 70	3,000
			Large 90; 110	10,000
	Lauderia	*annulata*	35	1,000
	Leptocylindrus	*danicus*	7; 40	70
		minimus	3; 25	10
	Lithodesmium	*undulatum*	50	1,000
	Melosira	sp.	30	700
	Odontella	*aurita*	Small 15; 45	300
			Large 40; 55	600
		mobiliensis	50; 70	3,000
		regia	Small 80; 90	5,000
			Medium 150; 150	10,000
			Large 250; 150	20,000
		rhombus	110; 60	4,000
		sinensis	Small 140; 140	5,000
			Large 250; 220	25,000
	Paralia	*sulcata*	20	300
	Podosira	*stelliger*	45	1,000
	Porosira	*glacialis*	40; 30	1,000
	Rhizosolenia	*alata*	10; 250	700
		delicatula	12; 45	200
		fragilissima	15; 45	300
		hebetata	15; 300	1,500
		pungens	10; 250	1,000
		robusta	80; 700	150,000
		setigera	Small 8; 200	500
			Medium 15; 300	1,500
			Large 30; 500	13,000

Table 7 (Contd.)

Group	Genus	Species	Size (μm) [a]	Carbon (pg C indiv.$^{-1}$)
		shrubsolei	Small 8; 200	500
			Large 20; 300	2,000
		stolterfothii	Small 20; 50	500
			Large 35; 80	1,300
		styliformis	40; 600	20,000
	Skeletonema	*costatum*	Small 5	10
			Large 12	30
	Stephanopyxis	*turris*	50; 55	2,000
	Streptotheca	*thamesis*	70; 110	1,700
	Thalassiosira	*anguste-lineata*	40	900
		eccentrica	60	3,000
		minima	12	50
		nordenskiöldii	25	300
		punctigera	50	1,700
		rotula	45	800
		sp.	10	40
			20	200
			30	500
			45	1,000
	Triceratium	*favus*	50	1,000
	Trigonium	*alternans*	35	300
Pennate diatoms	*Asterionella*	*glacialis*	8; 60	20
		kariana	4; 30	20
	Bacillaria	*paxillifer*	5; 70	50
	Brockmanniella	*brockmannii*	5; 25	25
	Cylindrotheca	*closterium*	5; 120	30
	Delphineis	*suriella*	10; 30	150
	Fragilaria	sp.	10; 40	150
	Gyrosigma	sp.	Small 15; 70	200
			Large 30; 120	1,000
	Navicula	sp.	Small 10; 40	100
			Large 30; 80	1,500
	Nitzschia	*delicatissima*	3; 50	10
		longissima	4; 110	20
		seriata	Small 5; 70	50
			Large 6; 120	120
	Pennales	Indeterminable	8; 40	100
			15; 60	300
			20; 80	500
			25; 120	1,000
	Pleurosigma	*elongatum*	12; 70	180
		sp.	25; 100	700
	Rhaphoneis	*amphiceros*	30	130
	Stauroneis	*membranacea*	60; 30	900
	Thalassionema	*nitzschioides*	4; 48	50
Flagellates	*Amphidinium*	sp.	Small 15	50
			Medium 25	100
			Large 40	500
	Cachonina	*niei*	15	80
	Ceratium	*furca*	50; 250	4,000
		fusus	40; 700	3,000
		horridum	45; 300	4,000
		lineatum	40; 150	1,500
		longipes	50; 200	4,000
		macroceros	60; 300	5,000
		tripos	80; 350	10,000
	Coccolithophorids	Indeterminable	Small 5	5
			Large 15	100
	Ctyocha	*speculum*	25	200
	Dinoflagellates	Indeterminable round	10	30
			20	300
			30	800
			45	2,000
			50	2,500
			60	5,000
			80	10,000
			100	15,000

Table 7 (Contd.)

Group	Genus	Species		Size (µm) [a]	Carbon (pg C indiv.$^{-1}$)
		Indeterminable flat		30; 20	200
				45; 25	500
				60; 30	1,000
				80; 45	3,000
				90; 45	4,000
	Dinophysis	*acuminata*		45	800
		acuta		70	2,000
		caudata		90	2,000
		norvegica		60	2,000
		rotundata	H	45	1,000
	Dissodinium	*pseudolunula*		25; 130	1,000
	Ebria	*tripartita*	H	25	200
	Exuviaella	*baltica*		12	40
	Flagellates	Indeterminable		3	3
				5	5
				6; 10	20
				8; 15	40
				10; 20	70
				15; 25	300
	Fragilidia	*subglobosum*		40	1,000
	Gonyaulax	*spinifera*		35	1,000
	Gymnodium	*sanguineum*		40	800
		sp.		20	100
				35	500
				40	900
				50	2,000
	Gyrodinium	*aureolum*		25	400
		sp.		20	200
				50	1,300
				75	4,500
				100	10,000
	Heterocapsa	*triquetra*		12; 25	100
	Noctiluca	*scintillans*	H	500	200,000
	Phaeocystis	sp.		Small 6	10
				Large 10	20
	Polykrikos	*spec*	H	Small 80; 45	4,000
				Large 150; 60	15,000
	Prorocentrum	*micans*		Small 30; 50	600
				Large 5; 70	2,000
	Protoperidinium	*brevipes*	H	25	500
		claudicans	H	75; 60	7,000
		conicum	H	75; 60	7,000
		depressum	H	150	20,000
		divergens	H	80; 55	8,000
		ovatum	H	60; 70	9,500
		pellucidum	H	50	4,500
		punctulatum	H	55	5,000
		sp.	H	25	500
				35	1,000
				45	2,000
				60	5,000
				80	10,000
	Pyrophacus	*horologicum*		80; 50	6,500
	Scrippsiella	*trochoidea*		20; 25	500
	Torodinium	*robustum*		55; 22	750

[a] In the size column normally the numbers indicate the diameter of the cells. If there are two numbers the second one is the length

ferent investigators. Although we have now cleaned up the database, there are still likely to be random errors which currently are impossible to eliminate completely as it would require the revision of more than 8,300 samplings. All the notes in the lists drawn up are only based on the experience and estimates of the authors, the literature on the basis of the available data, and detailed questioning of the original investigators.

The quality control we carried out on the Helgoland phytoplankton time-series data has been particularly difficult because of the lack of documented meta-information, the lack of permanent preparations and the unavailability of good photographic evidence. Had it not been for the fact that most of the original sampling and counting personnel were extremely helpful and still contactable, our task would have been next to impossible. We have, as a result of these problems, rethought our strategies for long-term assessments of phytoplankton species at Helgoland. We propose the following improvements:

1. Samples should be counted immediately.
2. The person counting the samples should take part in a national counting and identification quality control programme.
3. For taxonomic evaluation (e.g. to update the checklists), twice weekly net haul samples should be taken for detailed observations on live material.
4. All meta-information and count data should be regularly archived in www.pangaea.de.
5. Accurate photographs (under an excellent microscope) of the species should be taken, if necessary.
6. Samples should be kept for 10 years, which although not fail-safe due to the disintegrative processes allows some backtracking.
7. Samples should be regularly preserved as permanent slides so that the species spectra are archived for posterity, allowing retrospect taxonomic evaluations.
8. The taxonomic characteristics and classification criteria are currently being made available to all via the Helgoland Plankton*net web site and a handbook should be published shortly.

The very arduous quality control of this historic data set is not yet complete. We still have to estimate if it would be worthwhile adding the species missing from the electronic data set but recorded on paper to the set. Isolated species may still be inaccurate and should be removed. Perhaps the most important task ahead is to completely recalculate the carbon concentrations based on the size classes of the algae. However, we are now confident that we can free up large sections of this historic data set for use in biodiversity questions and questions on change in the North Sea.

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Appendix

Tables 6 and 7 show two Helgoland Reede checklists, updated in 1970 and 1991, respectively.

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