Helgoland Roads time series: learning from long-term marine data sets

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Abstract

Helgoland Roads time series, especially the pelagic time series, serve here as an example of how important continuous time series are for understanding marine ecosystems. Using these data sets the problems associated with long term data acquisition and analyses are elucidated, including quality control examples as well as error examples. The need to differentiate between trends and shifts is discussed. We show the need for having a vigilant unbiased view of the occurrence and persistence of new species.

The greatest challenges with long term marine data are identified as:
- producing a reliable quality-controlled data set,
- posing relevant unbiased hypotheses and
- finding the correct points of analyses and analytical methods.

Introduction

In times of rapid change and increased pressure on resources, as many of our marine systems are currently experiencing, the foresight shown by scientists, naturalists and managers with the introduction and continuation of Long Term monitoring programmes is laudable.

We are fortunate in particular that in shelf seas and basins many data sets exist. These are increasingly taken out of the closets and subjected to scientific scrutiny. These data sets range from spatially gigantic (such as the CPR) data series (Reid et al., 1998) highly temporally resolved such as the Helgoland Roads time series (Wiltshire et al., 2008), including very old Benthic time series at Helgoland showing gaps of tens of years (Bartsch et al., 2004).

A good long term data set can be a mine of information and the temptation may be large to analyse it indiscriminately, for example to look for climate induced changes. Yet a good dose of scepticism and meta data analyses are needed. In particular, when data come from systems such as the North Sea which in the last 100 years has experienced repeated overfishing, large scale dredging, coastal defence and dyke construction, increased and decreased pollutant loading as well as warming, hypotheses on changes in ecosystem structure and function cannot be based on single factors alone. When dealing with trophic cascades and food webs it is important to involve these complex interactions into ones’ considerations.
Here we present and discuss examples of long term data characteristics, problems and results, based on the temporally highly resolved Helgoland time series both in the pelagic and benthos, to a lesser extent.

DATA

The data sets of the Helgoland long-time sampling series are potentially the richest temporal marine data sets available. They include daily surface water sampling, resulting in a pelagic data set of the Helgoland time series comprising phytoplankton, salinity, Secchi and nutrients analyses from 1962 until the present day. Concurrently the biological parameters zooplankton, rocky shore macroalgae and macro-zoobenthos and bacteria were sampled discontinuously until the 1990s and only recently have been sampled again on a regular basis.

These data sets are used for many purposes, e.g., monitoring the pollution status of the German Bight and the North Sea or, providing ground truth information for Remote Sensing activities. They are implemented as forcing for predictive ecosystem and climate models and they used as a basis for governmental decisions and directives such as the EU ‘Water Framework Directive’.

Because of the potentially high profile which data sets acquire in management strategies, quality assurance and archival are of paramount importance.

While the pelagic parameters have been extensively quality-controlled, the benthic data sets are difficult to check due to lack of consistent long term records and reference sites. Indeed for the rocky shore benthic time series a large amount of time and effort has been invested in trying to link up different data sources. Due to differences in sampling strategies, nomenclature and recording techniques, it proved next to impossible to carry out comparisons between old and new data sets beyond looking at presence and absence of species. However, the pressure is on with regard to the distinction between climate and other signals in coastal seas often leaving the user little time for quality assurance.

Quality and accuracy of data is a major issue in producing and using long-time series data. Unfortunately in practice, this is frequently overlooked and rigorous data control is rarely in evidence.

The pelagic time series of Helgoland Roads (with the exception of zooplankton data that are currently being revised) have been successfully amalgamated into an open access data bank (<www.Pangaea.de>), cross-checked with other data sets from the same water bodies and reference data sets for the North Sea (Wiltshire and Dürselen, 2004; Raabe and Wiltshire, 2008). With this, the pelagic data sets are now sufficiently understood, and corrections, problems and errors have been documented. Thus, they may be used confidently to assess long term changes to the North Sea pelagic ecosystem. The primary sampling at Helgoland Roads is carried out as it always has, with the introduction of a highly resolved automated monitoring system (FERRYBOX) has been introduced in order to understand the temporal variability on an hourly basis of temperature, salinity, nutrients and fluorescence at the site. Every two days light penetration is measured and compared with Secchi and chlorophyll measurements at the sampling site. Phytoplankton species lists are updated and an open access taxonomic database Plankton* Net (<www.planktonnet.eu>) has been established and is cared for by the AWI.

For the rocky intertidal long term monitoring at Helgoland, reliable and consistent intertidal sampling programmes associated with extensive mapping programmes have been introduced recently both for flora and fauna (Bartsch et al., 2004; Reichert et al., in press). The monitoring authorities have taken over a large proportion of the difficult sublittoral monitoring (Boos et al., 2004) which should ensure continuum and comparable long term data for the future. In the meantime because of the need to react to special situations – for example new species entering the system (both as introduced neobiota and as immigrants) – specialised sampling is carried out e.g. for several isopods and amphipods (Franke and Gutow, 2004) and for the ctenophore Mnemiopsis (Boersma et al., 2007).
Examples of problems in long-term data analyses

Nutrient data variability

All the nutrient data from Helgoland Roads are measured by colorimetric chemistry and photometers. These measurements, though standard, are not trivial. Lamps and optical filters as well as standards and calibrations have to be checked regularly and the knowledge on how rigorous this needs to be has developed over the years. Consequently, we spent a lot of effort in ensuring that the methods and calibrations used in the past were up to standard and that the data archived were usable and comparable over time. Perhaps the best way to demonstrate the type of problems encountered in long-term nutrient analyses is using the silicate data from Helgoland Roads.

Figure 1 shows the silicate values from 1962 to 2005. What stands out is the fact that there is a large jump in the data set around 1987. Over the years this was thought to have been due to inaccurate calibration. However, the continuous decline in values observed thereafter, symptomatic of a system which had a large nutrient input subsequently sequestered, led us to further investigate this jump in the data. As described in Raabe and Wiltshire (in press) a time period was chosen when normally nutrient remineralisation is almost over (even for silicate) while microalgal activity is still at its minimum, i.e. the mid winter month- February. Additionally, in February, the river discharge into the German Bight also would not have reached its maximum and thus, the nutrient concentrations at Helgoland Roads should not have been affected much by phytoplankton growth and/or river discharges extending into the German Bight.

Raabe and Wiltshire (in press) showed that from 1966 to 1986, a significant decrease from almost 15 µM down to < 5 µM was observed in February medians. In 1987, the February median increased, culminating in a peak of > 25 µM in 1988. Thereafter, the medians of silicate concentrations slowly decreased again, but did not reach the low level of < 5 µM that had been registered before 2003. Regression analysis for the years 1990 through 1999 gave a highly significant linear correlation (p < 0.001), with a winter silicate decrease of 0.75 µM year⁻¹.

We compared these German North Sea data, Raabe and Wiltshire (in press) data from British research cruises of the same time downloaded from the ICES database. The results showed a clear upwards trend from 1985 to 1987, when the overall silicate concentrations reached > 20 µM in coastal waters. All the cruise data values were very similar, confirming the good quality of the...
independently sampled and analysed data. Starting with concentrations of 5 µM in 1984, the means reached almost 8 µM in 1987, and then dropped back to a nearly constant level of < 5 µM from 1988 through 1991. This clearly indicates a strong silicate input into the North Sea during the year 1987.

After 1990 the Helgoland Roads silicate values never dropped back to the very low concentrations recorded in the early 1980s, although it seems that the silicate is slowly being sequestered in the system, indicated by a steady downward trend in concentrations.

Detailed analyses of the literature and hydrographic conditions regarding inflow from rivers as well as a sudden shift in a whole array of biological parameters in 1987-88, lead us to accept this “hike” in silicate values as real.

Reid et al. (2001) reported that “phytoplankton colour”, a visual estimate of chlorophyll from the CPR, increased in the North Sea after 1987 thus conforming these observations. Many phytoplankton and zooplankton species showed marked changes in abundance. Catches of horse mackerel (Trachurus trachurus L.) increased, indicating a northerly range expansion from the Bay of Biscay into the North Sea after 1987. Wiltshire et al. (2008) show a marked increase in microalgal densities around this time. Edwards et al. (2006) investigated the long-term spatial variability of Harmful Algal Blooms (HABs) in the northeast Atlantic and the North Sea using data from the Continuous Plankton Recorder (CPR) and showed unusually high values for the inter-annual bloom frequencies in the late 1980s. They related this to the North Atlantic Oscillation (NAO).

Counting organisms and species identification

Perhaps one of the greatest problems when maintaining a long term data set is the enumeration and identification of species. The Helgoland Roads Phytoplankton time series provides a good example of the problems incurred.

The main difficulty is to achieve conformity when identifying species. This is made more difficult when there are diverse people involved. At Helgoland Roads ten people counted over the time period 1962 through 2007. Although every effort was made to have counting overlap and species intercalibrations along the way, we know from our detailed analyses of the data (Wiltshire and Dürselen, 2004) that there are many problems which can be related to changes in counters.

Fig. 2. Flagellate cell numbers-Helgoland Roads.
An example was given in Wiltshire and Dürselen (2004) which we cite again here: Is the observed increase in flagellate numbers in 1976-1978 (Figure 2) really related to increased nutrient input due to eutrophication, or related to a change in hydrographical regime, or is it rather related to the involvement of a new counter? One thing is for sure: the enormous increase in flagellate counts in 1998 is related to the purchase of a new microscope. Interestingly such problems seem to have been negligible for the larger and more easily identifiable diatoms. Thus, one really has to save and use the meta-information related to counting persons carefully.

Experience shows that here it is already difficult to count and analyse small organisms even only as general classes under the microscope. It is next to impossible to achieve undisputed accuracy to species level. In the Helgoland Roads data set this is in evidence on a daily basis, for example with small dinoflagellates where we usually just get it down to genus (e.g. *Protopteridinium* spp. and *Gyrodinium* spp.). We now document this clearly and make type slides of our phytoplankton on a monthly basis. We also pick out previously unclearly identified species and try to get them into culture, also using molecular techniques (e.g. most recently *Peridieliella danica* and *Thalassiosira* species). In the past a few problems have arisen due to the fact that species were not clearly identified. The best example is the diatom *Coscinodiscus wailesii* which was “found” in the Helgoland Roads lists at least two years before it was recorded elsewhere in the North Sea. As no type material was archived and the paper notes are ambiguous, it was likely erroneous. As a result we currently not only take daily samples for Utermöhl counting, but also weekly samples for “species hunts” using nets of different mesh sizes. We try to even take pico and nano phytoplankton into our sampling regime at regular intervals because we are aware of the fact that although we can only identify them with optical and molecular tools, they may be of pivotal importance to the lower part of the food web.

Similar problems exist for zooplankton. Many species, including important indicator species such as the copepods *Calanus hegolandicus vs. Calanus finmarchicus*, have only been identified to genus level. This is frustrating as we now really need them to confirm some of the hydrographic shifts and related trophic changes observed in the North Sea. Thus, we now take more time to differentiate them and are examining ways to reanalyse old data. Although we are absolutely certain that we have found *Mnemiopsis leyidii* in 2006 (Boersma et al., 2007), it is distinctly possible that this organism has been there for longer: as suggested by Faasse and Bayaha (2006) it could have been mixed up with *Bolinopsis* for quite a while because nobody was expecting it and/or had the knowledge to recognise it. Thus, for zooplankton a new analyses regime has to be introduced as well as a stringent documentation of the status quo in the coming months. As for the phytoplankton we have begun to sample size classes that are consequently difficult to identify - e.g. ciliates and mesoplankton in general over the past three years. The outcome was as expected: they are very abundant, voracious feeders and we have identified many species which should not be ignored in long term marine observations.

Among the Helgoland hard-bottom macrofauna some 30 species which had never been reported before for the German Bight or even the North Sea, were registered as permanent elements of the community over the past three decades. As far as these species are conspicuous in phenotype and easy to classify, they may represent true newcomers, e.g. the isopod *Idotea metallica* (Franke et al., 1999), the crab *Liocarcinus depurator* and the hermit crab *Diogenes pugilator* (Franke and Gutow, 2004). Some “new” species, however, particularly amphipods and polychaetes, may have been overlooked or confused with other species in former times. This may apply to *Jassa herdmanni* (Amphipoda), the most abundant species of the genus, which may not have been differentiated from its similar congener *J. falcata* previously (Franke, unpublished). The Japanese skeleton shrimp *Caprella mutica* (Buschbaum and Gutow, 2005; Cook et al., 2007). *Caprella linearis* (Buschbaum and Gutow, 2005: Cook et al., 2007).

**Knowing what one wants: trends vs. shifts**

The current true long term data sets (over 20 years), were often set up with a naturalist’ curiosity as the driving force. Earlier oceanography realised the need for taking many repeated samples over very long time periods and large scales (see CPR data set for example) in the world’s oceans.
At the beginning of the previous century it was realised that rapid change, mostly anthropogenically induced, could also affect marine systems. In order to assess changes, monitoring time series were set up. Helgoland Roads is an example. The number of questions to which data sets are applied has grown over time. At Helgoland Roads we have many more questions then the original questions posed, for example:

- How did/does overfishing affect the system?
- How does the introduction/occurrence of new species/aliens affect the system?
- How does climate change influence the system?
- How does changing hydrography affect the system?

Because the system is multi-layered, with countless trophic interactions and input variables, the questions posed above cannot be seen in isolation. Thus, one has to go beyond simple cause and effect analyses based on linear assumptions and must venture into multi-variate statistics and non-linear modelling.

One of the most common problems associated with time series is their time span: after how many years can one use them for prophesies? Geologists, for example, often maintain that only geological time scales are important. This may indeed be the case if one does not consider human-induced changes to an ecosystem. One of the most common assumptions made with the conservative variable temperature is that one can make decent prophesies from a mere ten years of data. An example of how the ten year blocks for Helgoland Roads look like relative to the overall prognosis based on the 45 years of time series is given in Figure 3. There one clearly sees that the linear regressions, all significant trends, for ten year blocks are very different and deviate substantially from the linear trend for all 45 years (Figure 4). None of these would have provided a simple and accurate prognosis for the subsequent 20 years let alone 100 years. On the other hand, it is important to compare different climatic blocks of data— as in cold year blocks versus warm year blocks. Sudden shifts in temperature are also important, e.g. warm to cold shifts as seen in 1986-89 and 1996, since these can cause sharp shifts in biological systems and even reset a system (Reid et al., 1998; Edwards et al., 2002; Straile, 2002; Weijerman et al., 2005; etc.).

![Fig. 3. Temperature trends for separate 10 year mean blocks-Helgoland Roads.](image-url)
Thus one needs to differentiate the effects of trends versus sudden changes or repetitive shifts in the system (see Ottersen et al., 2005).

Simple biological questions such as: does temperature affect the timing of the spring bloom of microalgae? become a challenge in systems like the German Bight which is differentially affected by coastal and marine currents depending on larger weather patterns (see Radach, 1998; Wiltshire et al., 2008; etc.). Indeed the longer a time series, the more interesting such questions become because the more likely we are to understand what is really going on. At Helgoland Roads an analysis of older data until 2000 showed that in general the spring bloom came later related to warmer autumns and potentially due to top down control by surviving herbivores (Wiltshire and Manly, 2004). However, once later data were included this trend was no longer clear and the timing of the spring bloom now appears related only to temperature, it is now coming earlier rather than later. This shift in trend means that overall nothing has changed in timing over the 45 years, statistically speaking, but it is certain that the first thirty years behaved differently from the past 15 years. We went to considerable lengths to evaluate this (Wiltshire et al., 2008) with the data available to us and are at the stage where we need to model interactions to understand the governing parameters in the timing of the bloom. Here again it is important to differentiate out sudden shifts, clearly seen for the spring bloom data in the time period 1975-1979 (Wiltshire and Manly, 2004), versus trends.

**Unbiased views: introduced species**

New species are continuously arriving in marine systems both naturally as immigrants and through human input. Some of the most controversial introductions in the past have been via ship ballast water, including toxic microalgae into the Northern North Sea, or the introduction of the voracious comb jelly *Mnemiopsis leidyi* to the Caspian Sea with disastrous consequences. The North Sea has been subject to many species introductions such as the Pacific Oyster into the Wadden Sea which is becoming extremely extensive and which is likely to have had an effect on the planktonic organisms due to heightened filtering of the water column in the German Wadden Sea (Kochmann et al., 2008) not to speak of the concrete-like substrate which it induces in a habitat which used to be dominated by *Mytilus edulis*. In the phytoplankton new species have arrived from all over the world in the past 40 years at Helgoland Roads, such as *Concinodiscus wailesii* and *Odontella*

![Graph showing mean yearly temperature trend](image-url)
*sinensis* to name but two. As yet we do not know whether these two species have had any effect on the planktonic system.

An aspect of great concern in climatically affected systems such as the North Sea is the introduction of “warm climate aliens”, or rather species that have arrived in the system and normally would die off under colder conditions but which now can persist and multiply. Many examples of these at Helgoland Roads are found in the larger organisms, including the brown seaweed *Sargassum muticum* (Reichert and Buchholz, 2006) and the isopod *Idotea metallica* (Gutow and Franke, 2001). As a geologically young ecosystem, the southern part of the North Sea may be expected to be ecologically ‘unsaturated’, able of supporting much more species than at present.

Introductions are normally considered as being negative- however, this is a rather biased assumption- often based on very negative examples. *Sargassum muticum* for example, a recent introduction into the German Wadden Sea is a refuge for small fish and a gathering point for plankton- seemingly making it a positive introduction to the Wadden Sea by increasing habit at value (Polte and Buschbaum, 2008).

The whole issue of introduced species is understandably sensitive in systems which have been dramatically affected by these. However, at present although we are vigilant at Helgoland Roads we try to keep an open mind on the subject as most of these introductions over the past 45 years (certainly in the phytoplankton) seem to have been absorbed into the system.