

Indicators for ecological status of angiosperms and charophytes in Danish coastal waters

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Summary

Until now, indicators of ecological state of Danish coastal waters on the basis of marine vegetation have encompassed eelgrass (*Zostera marina*) and red, brown and green macroalgae growing on hard substratum. By contrast, charophytes (a division of macroalgae) and angiosperms other than eelgrass have not previously been explored in this context.

In this research note, we fill this gap by investigating, based on Danish monitoring data, the potential for developing ecological indicators of angiosperm species other than eelgrass as well as charophyte species. For these groups we explored the potential to use maximum depth limits (i.e. the deepest occurrence of shoots), main depth limits (i.e. the deepest occurrence of patches of 10 % coverage), and the cumulative cover (i.e. sum of all species' cover) at a given water depth.

Transect data on species-specific cover and depth limits obtained from the national monitoring programme have been analysed using statistical models resolving the spatial and temporal heterogeneity of these data. Trends of cumulative cover and depth limits for angiosperms (excluding eelgrass) and charophytes have been calculated and investigated in relation to Secchi depth and nutrient levels.

Charophyte data are generally sparse and restricted to areas of relatively low salinity, with just one area (Guldborgsund) having sufficient data for analyses of trends in depth limits and just four areas having sufficient data for exploring trends in cover. Therefore, indicators were associated with large uncertainty and were not linked to eutrophication pressures. Consequently, the monitoring data do not support the development of charophyte indicators for assessing ecological status of Danish coastal waters.

Angiosperms were more common than charophytes in the most brackish Danish coastal ecosystems, and indicators developed on angiosperm data were relatively precise, particularly depth limits that also exhibited clear linkage to Secchi depth. The precision of angiosperm depth limits can be improved by increasing the number of monitored transects or increasing the focus on examining their depth limits along existing monitoring transects. Angiosperm cover data were more variable and did not exhibit the same strong linkage to pressures such as light conditions. On this basis, we conclude that angiosperm depth limits are useful for assessing ecological status of brackish and sheltered coastal ecosystems.

1 Introduction

According to the European Water Framework Directive, the ecological status of a water body should be assessed from the status of a number of Biological Quality Elements (BQE) through the one-out-all-out combination rule. For coastal water bodies, the BQEs are phytoplankton, benthic vegetation and fauna. The BQE benthic vegetation includes the status of both angiosperms and macroalgae.

For Danish coastal waters, a range of macroalgae indicators for hard bottom substratum have been developed previously (Carstensen et al. 2008, 2014) and are currently under implementation (Carstensen 2017), but for angiosperms there is only one indicator available at present, the depth limit of eelgrass.

Since Danish coastal waters inhabit more angiosperm species than eelgrass (*Zostera spp.*), the potential for deriving additional ecological indicators, based on other angiosperm species, should be investigated. Furthermore, since charophytes (a division of macroalgae) are also present on soft seafloors of the more brackish coastal water bodies, potential ecological indicators based on charophyte species should also be analysed. Therefore, the objective of the current note is to investigate the potential for such indicators.

Eight criteria have been identified for the quality of an indicator (Quiéros et al. 2016):

1. It should be underpinned by a strong scientific basis of causal linkages to given pressures.
2. It should be relevant to the ecosystem in question.
3. It should be responsive to one or multiple pressures, implying that significant changes in the indicator are expected within realistic ranges of pressures.
4. It should be possible to set targets for the indicator, i.e. reference conditions and class boundaries.
5. It should have a response time to pressures that enables mitigation.
6. It should be quantitatively measureable and precise.
7. It should be cost-effective.
8. It should be assessable over time, implying that longer time series should be available.

These eight criteria will be used for assessing the quality of the proposed indicators in the concluding section discussing the potential for indicators.

In relation to criterion #2, charophytes and angiosperms are known to have ecological relevance in shallow freshwater and brackish ecosystems (Schneider et al. 2015). With respect to criterion #1 and #3, charophytes, in particular, are known to be very sensitive to reduced water quality and, hence, have the

potential to be responsive indicators of ecological quality (Blindow 2000). Indeed, the presence and depth penetration of charophytes and angiosperms are highlighted as important indicators of ecological quality in the brackish and protected German boddens where they thrive in clear waters with low nutrient concentrations, while they do not occur along the coastline outside the boddens (Selig et al. 2007). Charophytes are also known as sensitive indicators of water quality in Danish freshwater environments (Baastrup-Spohr et al. 2013; Sand-Jensen et al. 2017), and there are reports on reduced occurrence of charophytes in response to eutrophication in e.g. Randers Fjord (Nielsen et al. 2003.). Here, we further explore the sensitivity of depth limits and cover of charophytes and angiosperms in Danish coastal waters based on monitoring data.

2 Data for angiosperm indicators

2.1 General description of data

Angiosperms and charophytes have been monitored in parallel with eelgrass along transects in Danish estuaries and coastal waters. Angiosperm species in Danish coastal waters mainly belong to the genera *Zostera*, *Ruppia*, *Zannichellia* and *Potamogeton*, whereas charophytes are almost entirely species from the genus *Chara* (Manscher & Krause-Jensen 2010). Since eelgrass indicators have already been developed and the focus of this research note is to explore and potentially develop indicators for other soft-bottom vegetation, we will refer to angiosperms as those species mentioned in *Table 2.1* and charophytes as those species mentioned in *Table 2.2*.

Data extracted from the national database (ODA) were collected as part of the National Monitoring and Assessment Programme for the Aquatic and Terrestrial Environment (NOVANA) and regional monitoring activities. The monitoring of soft-bottom vegetation in Danish coastal waters involves recording of coverage and depth limit of individual species along transect lines based on diver or video surveys. Until 2001, divers visually assessed the cover of the various species as averages for a depth interval but since 2001, the recordings are done continuously for consecutive points along the transects. The transects are T-shaped: The main transect extends perpendicularly from the coast until the maximum depth limit (i.e. at the deepest shoot) is reached, after which 5-7 additional point observations of the maximum depth limit are obtained along a line parallel to the shore, resulting in the T-shape. The 'main depth limit' is assessed along the main transect as the deepest occurrence of 10 % vegetation cover.

2.2 Data set for vegetation depth limits

Depth limits for angiosperms and charophytes were not monitored as consistently as for eelgrass, but nevertheless there were >10000 recorded max depth limits for angiosperms and >2000 for charophytes. There were only 1485 main depth limits for angiosperms and 237 for charophytes. For angiosperms, depth limits were recorded for 15 taxonomical classifications within the genera *Potamogeton*, *Ruppia* and *Zannichellia* in addition to the species *Batrachium baudotii*, *Myriophyllum spicatum*, *Nuphar lutea* and *Sparganium emersum*. For charophytes, depth limits were recorded for four taxonomical classifications within the genus *Chara* as well as for the species *Tolypella nidifica*. Multiple depth limits may be recorded on a single transect (when the diver swims perpendicularly to the transect at the outer depth limit) and these were averaged to provide one observation per transect per day of investigation. This resulted in 1090 and 321 max depth limits for angiosperms and charophytes, respectively, and similarly in 1440 and 351 main depth limits for angiosperms and charophytes. With the exception of a single max depth limit, all depth limits were recorded after the method change in 2001 so that they represent the period 2001-2016. The depth limits were observed across a broad range of coastal sites, though with few observations in each of the sites.

In order to have sufficiently large data sets for analysis, we restricted the analysis of depth limits to coastal sites with at least 32 observations, corresponding to ~2 per year for the study period (2001-2016). Consequently, depth limits of angiosperms were analysed for 10 coastal sites, whereas there was only one

coastal site (Guldborgsund) with sufficient depth limits for charophytes. Hence, the limited data for charophytes did not allow a general development of indicators.

2.3 Data set for vegetation cover

Over the years, many observations of vegetation cover have been recorded for both angiosperms (Table 2.1) and charophytes (Table 2.2). Most of the cover data before 2001 were assessed for depth intervals, whereas data after 2001 are depth-specific (Krause-Jensen et al. 2001). Compared to Manscher & Krause-Jensen (2010), who analysed data from 1982 to 2010, the number of species has increased slightly, and the number of cover observations has almost doubled. Importantly, our analysis also included zero observations, i.e. depth-specific observations where the species could be expected but did not have any cover at that specific sampling point. We calculated the cumulative cover of angiosperms and charophytes by summation over all species listed in Table 2.1 and Table 2.2, respectively.

Table 2.1. Number of cover observations for different species of angiosperms (ex. *Zostera spp.*) extracted from ODA (1982-2016). Cover was observed for depth intervals (older data) and as point observations (specific depths; newer data).

Species	N (depth interval)	N (depth)
<i>Batrachium baudotii</i>	410	40
<i>Batrachium circinatum</i>	28	44
<i>Blomsterplanter, uspec.</i>	92	
<i>Callitriche sp.</i>	3	36
<i>Ceratophyllum demersum</i>	4	210
<i>Elodea canadensis</i>	6	179
<i>Myriophyllum spicatum</i>	292	960
<i>Nuphar lutea</i>	11	115
<i>Nymphaea alba</i>	1	4
<i>Potamogeton crispus</i>	36	359
<i>Potamogeton filiformis</i>	1	
<i>Potamogeton obtusifolius</i>	19	93
<i>Potamogeton pectinatus</i>	3721	32663
<i>Potamogeton perfoliatus</i>	81	498
<i>Potamogeton polygonifolius</i>	1	
<i>Potamogeton praelongus</i>	1	
<i>Potamogeton pusillus</i>	7	18
<i>Potamogeton sp.</i>	1024	27284
<i>Ruppia cirrhosa</i>	2812	20352
<i>Ruppia maritima</i>	2359	23978
<i>Ruppia sp.</i>	1564	68964
<i>Sparganium emersum</i>		52
<i>Zannichellia major</i>	855	572
<i>Zannichellia palustris</i>	150	19278
<i>Zannichellia pedunculata</i>	17	229
<i>Zannichellia repens</i>	46	22
<i>Zannichellia sp.</i>	936	34213
Total	14477	230163

Aggregating the species-specific data over these two groups poses a challenge. For some depth-specific observations, angiosperms or charophytes may not have been recorded and hence, summation will lead to a missing value. If the depth-specific observation is part of the main transect, then the missing value should be replaced with a zero value, because no angiosperm

or charophyte species were observed, but they would have been recorded if they had been present. However, on the T-part of the transect, where usually only eelgrass is recorded, it may not be correct to assume a zero value for the cover of the angiosperm or charophyte species. Therefore, missing values for the cover of angiosperm or charophyte were replaced with zero observations along the main transect, but not along the T-part (identified by the database flag for recording max depth limit).

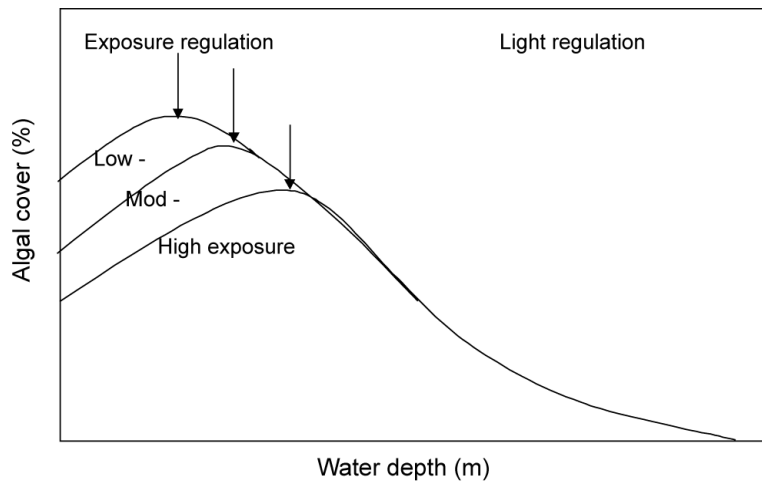
Table 2.2. Number of cover observations for different species of charophytes extracted from ODA. Cover was observed for depth intervals (older data) and as point observations (specific depths; newer data).

Species	N (depth interval)	N (depth)
<i>Chara aspera</i>	349	304
<i>Chara baltica</i>	119	1887
<i>Chara canescens</i>	111	
<i>Chara sp.</i>	556	32689
Charophyceae	4	
<i>Kransnåltalger, uspec.</i>		21
<i>Lamprothamnium papulosum</i>	40	1
<i>Tolypella nidifica</i>	522	1181
Total	1701	36083

The spatial distribution of occurrences of *Ruppia spp.*, *Zannichellia spp.*, *Potamogeton spp.* and *Chara spp.* was investigated by Manscher & Krause-Jensen (2010) and showed that they were observed in estuaries and coastal waters of the Belt Sea area, The Sound and the Baltic Sea. In this research note, we only focused on coastal sites that had at least 200 cumulative cover observations of angiosperms or charophytes, and where at least 10 % of these observations displayed cover (i.e. >0 % cover). This resulted in 17 and 4 coastal sites with sufficient data for analysing potential indicators for angiosperms and charophytes, respectively. Furthermore, only data after 2001 were considered due to the shift in monitoring from depth intervals to point observations.

The data analysis focused exclusively on angiosperms and charophytes from the depth range where physical disturbance was no longer a major controlling factor for cover by adopting the definition used for attached macroalgae (Carstensen et al. 2008) (see *Figure 2.1*). Carstensen et al. (2008) employed depth cut-off values of 1 m for weakly exposed areas, 3 m for moderately exposed areas and 5 m for highly exposed areas. Examination of cover versus depth for the different coastal sites revealed that light limitation started at shallower depths for angiosperms and charophytes than for attached macroalgae. The more exposed coastal sites typically had a cut-off value around 2 m and coastal sites with low exposure had a cut-off value around 1 m. The cut-off was even as low as 0.5 m for Hjarbæk Fjord.

Figure 2.1. Illustration of the hypothesis that vegetation cover in shallow water is reduced due to physical exposure while from intermediate water depth towards deeper water, vegetation cover is reduced in parallel to reductions in light availability. Consequently, maximum vegetation cover is found at intermediate water depths and is located deeper in more exposed areas. Arrows indicate cut-off depths for different levels of exposure.



In addition to the cover of angiosperms and charophytes, the cover of suitable soft-bottom substrate was also recorded. Since the cover of rooted vegetation can also be limited by lack of suitable substrate, we restricted the analysis of cumulative cover of angiosperms and charophytes to observations with at least 75 % suitable soft-bottom substrate, similar to the threshold used by Wikström et al. (2016).

Finally, the analysis was restricted to months from May to October, when most of the transects were surveyed; a few transects were carried out in November but these observations had substantially lower cover compared to the other months. Although the technical guidance recommends that sampling should be carried out between June and September, in practice the sampling season extends a bit longer.

3 Statistical analysis

Observations of cumulative cover of angiosperms and charophytes were used to develop indicators to describe changes over time, while accounting for the heterogeneity of the monitoring data with respect to their sampling in time (month), depth and transect as well as the diver-specific variation. Changes over time and among sites were subsequently linked to relevant environmental variables to assess if the indicator responded to eutrophication pressure.

3.1 Indicators for depth limits

Max (D_{max}) and main (D_{main}) depth limits of angiosperms were analysed with a statistical model describing variations over time and space:

$$D = site_i + month_j + year_k + site_i \times year_k + STATION_l(site_i) + DIVER_m$$

where $site_i$ described differences between the 10 coastal sites, $month_j$ described a common seasonal variation, $year_k$ described the time trend common to all sites, $site_i \times year_k$ described the site-specific time trend, $STATION_l(site_i)$ described the random variation among monitoring transects within a site, and $DIVER_m$ described the random variation caused by using different divers in the monitoring programme.

With this model, variations in the depth limits were partitioned across the different factors, and means for the site-specific depth limit, common trend and site-specific trends were calculated from the parameter estimate of the model. This means that site-specific means represent an average across all months (May-Oct) and years (2001-2016), and the common trend represents an average across all months (May-Oct) and sites (10 sites).

3.2 Indicators for cumulative cover

Variations in the cumulative cover of angiosperms ($n = 20763$) and charophytes ($n = 4722$) generally increased with cover levels, suggesting that these data should be described with a lognormal distribution. However, the distributions of cumulative cover were strongly zero-inflated with 43 % and 79 % of observations equal to zero for angiosperms and charophytes, respectively. Thus, we need to describe cumulative cover of angiosperms and charophytes with a distribution that accounts for the many zero observations. In such cases, a compound distribution is useful that combines a binomial distribution with a lognormal distribution. Therefore, we describe the observed cumulative cover as

$$cumcover = P(absence) \cdot 0 + P(presence) \cdot (cumcover|present)$$

where

$$P(presence) = g(site_i + depth + month_j + year_k + site_i \times year_k)$$

$$\begin{aligned} \log(cumcover|present) &= site_i + depth + month_j + year_k + site_i \times year_k \\ &+ STATION_l(site_i) + DIVER_m \end{aligned}$$

Thus, the presence/absence of angiosperms or charophytes is a binary variable where the probability of presence is a linear function of site, depth, month and year of the observation translated through the logistic link function $g()$. This model assumes that all sites display the same seasonal pattern and decreasing probability of presence with depth, although these relationships are displaced by the factor $site_i$ describing that some sites have generally higher probability of presence and some sites have generally lower probability of presence. The factors $year_k$ and $site_i \times year_k$ describe the common and site-specific interannual variations that are of interest for describing changes of time in indicators of soft-bottom vegetation. The model for cumulative cover when present ($cumcover|present$) contains the same factors and two random factors in addition that explain variation among transects within sites ($STATION_i(site_i)$) and variation among divers surveying the transect ($DIVER_m$). In other words, cumulative cover is modelled using two models: 1) one presence/absence binary model using all data and 2) a lognormal model for observations with cumulative cover >0 .

Distributions for the annual means of the common and the site-specific trends were calculated for probability of presence and cumulative cover when present. The means were calculated to represent a depth of 2 m, an average of all six months (May-Oct), an average of all transects within the given site and an average of all divers involved in the monitoring. Subsequently, these distributions were combined to describe the overall distribution of cumulative cover by Monte Carlo simulation, i.e. simulating 1000 outcomes of probability of presence and cumulative cover when present. The mean and 95 % confidence interval for the resulting distribution of the overall cumulative cover were calculated from the product of these two simulated distributions. Thus, the resulting trends account for variations in monitoring data regarding both presence/absence and cumulative cover when present. The mean cumulative cover for all sites was calculated similarly from the parameters of the model.

3.3 Linking depth limits and cumulative cover to environmental variables

Data on salinity, Secchi depth and nutrient concentrations (total nitrogen and total phosphorus) were extracted from the national database ODA using representative stations for the 15 sites with sufficient angiosperm observations and 6 sites with sufficient charophyte observations. Observations were averaged for the surface layer (0-10 m) and only observations after 2001 (corresponding to the criteria for vegetation) were used. Nutrient concentrations were log-transformed prior to statistical analysis. Variations in these environmental variables were described using a model similar to the above

$$Y \text{ or } \log(Y) = site_i + station_j(site_i) + month_k + year_l + site_i \times year_l$$

where $site_i$ described variations among sites, $station_j(site_i)$ described variation among monitoring stations within sites, $month_k$ described the seasonal variation for the same months as for vegetation, $year_l$ described the common trend for all sites, and $site_i \times year_l$ described the site-specific trends. After partitioning the variations of the environmental monitoring data into spatial and temporal sources of variation, site-specific means and trends as well as the common trend were calculated as marginal means from the model.

For investigating the relationship between indicators of depth limits for angiosperms and cumulative cover for angiosperms and charophytes versus potential pressures, we combined 1) site-specific means, 2) common trends for

all sites, and 3) site-specific trends. Potential relationships were investigated for cumulative cover versus Secchi depth, TN or TP. Salinity was also tested as an additional explanatory variable, but was not found significant for any model. No significant relationships were found for the cumulative cover of charophytes and therefore, for comparison, we present the relationship to the most significant explanatory variable for cumulative cover of angiosperms.

4 Results and discussion

4.1 Trends of depth limit indicators

Depth limits were relatively constant over the study period (2001-2016) for all investigated coastal sites with the exception of Nissum Fjord and Ringkøbing Fjord that both displayed significant trends of angiosperms growing out to deeper depths (Figure 4.1). In Nissum Fjord, this was most pronounced for the max depth limit (D_{max}) expanding from 1.2 m to 1.8 m, whereas the main depth limit (D_{main}) only increased from 0.7 m to 0.9 m over the 16 years. In Ringkøbing Fjord, the max depth limit almost doubled from 1.4 m to 2.5 m, whereas the main depth limit increased from 1.0 m to 1.5 m. Stege Bugt/Nor and Nakskov Fjord exhibited increases in both D_{max} and D_{main} , but the length of the time series was too short to conclude general deeper growth of angiosperms at these sites. On the other hand, Dybsø Fjord and Præstø Fjord both displayed decreasing depth limits over time. However, trends at Stege Bugt/Nor, Nakskov Fjord, Dybsø Fjord and Præstø Fjord were not significant. The average trend across all 10 coastal sites revealed a non-significant trend for D_{main} and a significant increasing trend for D_{max} from 2.6 m to 3.0 m over the 16-year study period. This trend was mainly driven by the results from Nissum Fjord and Ringkøbing Fjord.

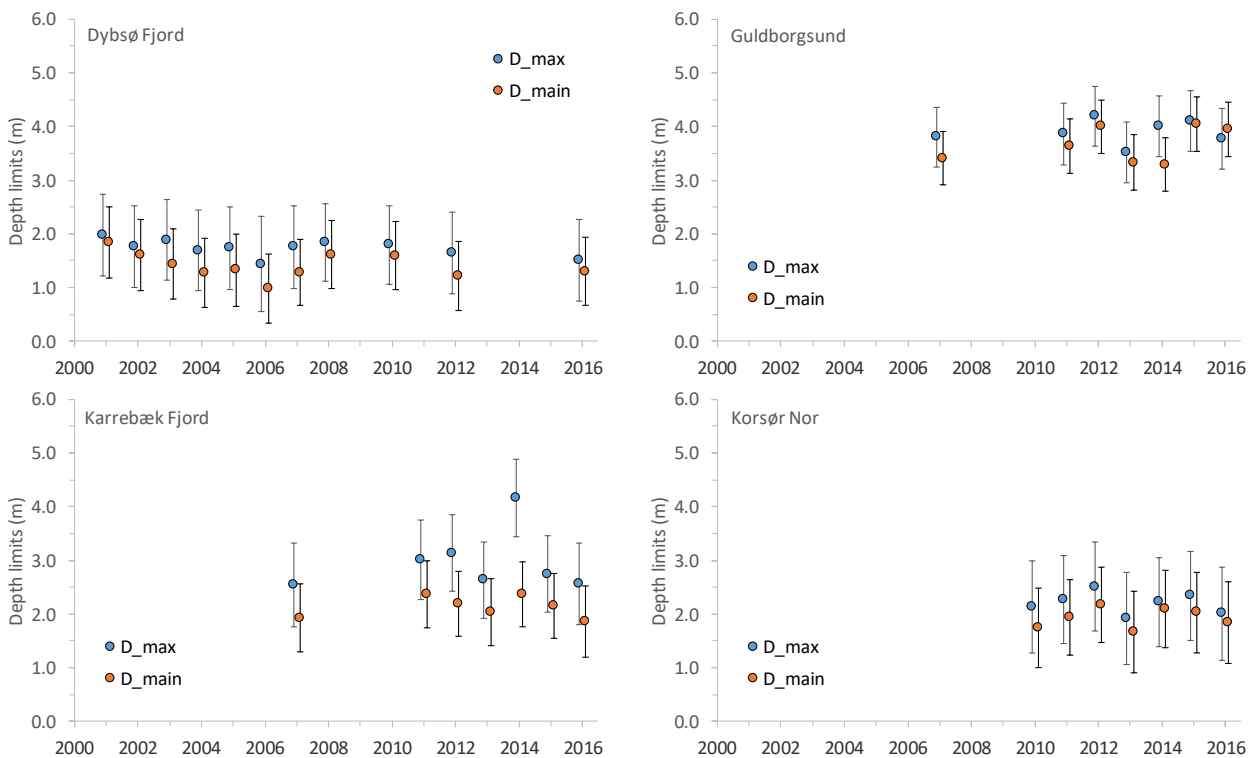


Figure 4.1. Annual means of angiosperm depth limits (D_{max} and D_{main}) for the 10 coastal sites with sufficient data as well as the common trend across all these sites. Error bars show the 95 % confidence interval for the annual means. Note that the scaling varies among sites.

Figure 4.1. continues on next page

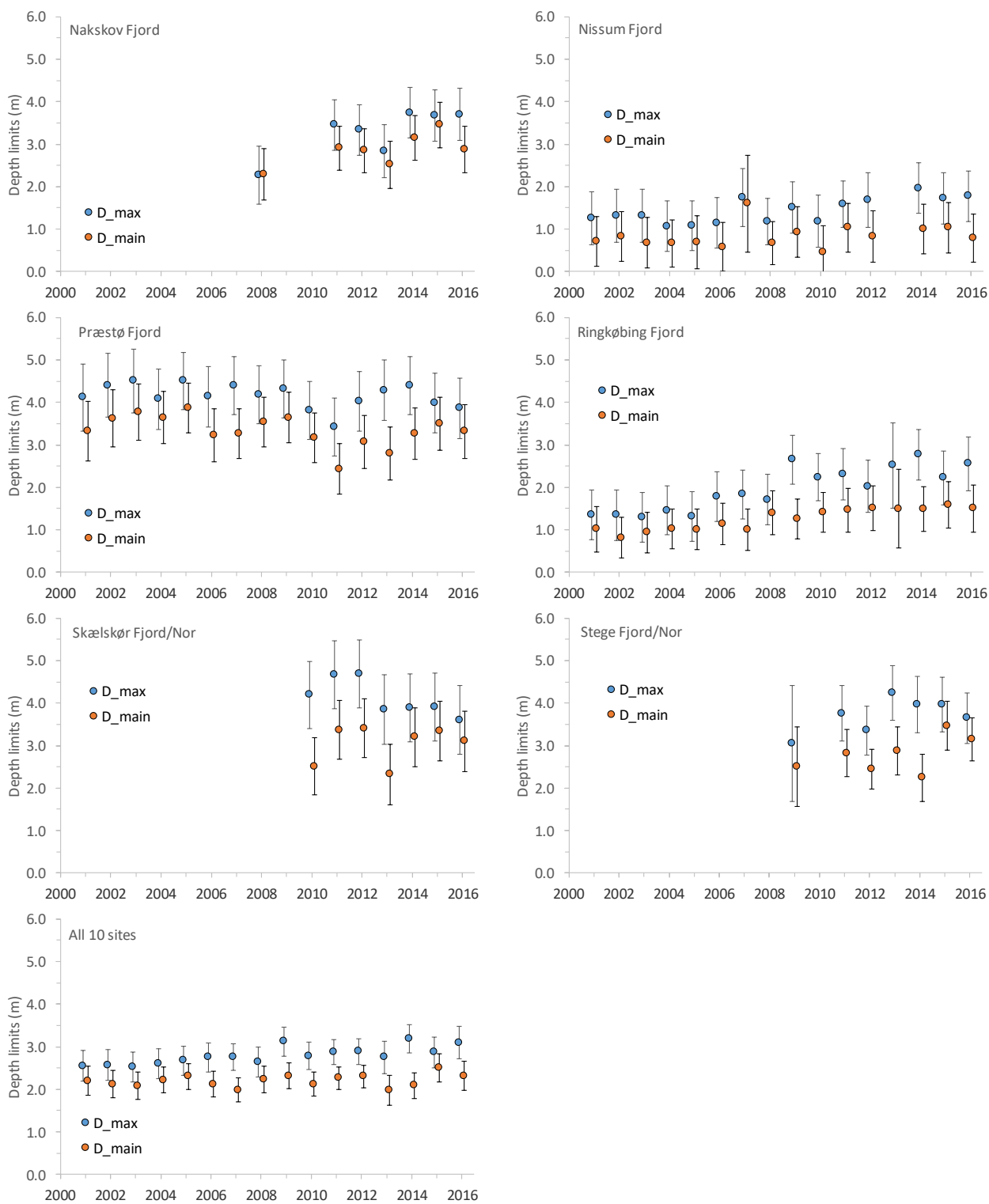


Figure 4.1. (continued) Annual means of angiosperm depth limits (D_{max} and D_{main}) for the 10 coastal sites with sufficient data as well as the common trend across all these sites. Error bars show the 95 % confidence interval for the annual means. Note that the scaling varies among sites.

4.2 Trends of cumulative cover indicators

The 17 sites with sufficient data on cumulative cover of angiosperms displayed a broad range of trends, varying in the overall mean level as well as in the direction of change over time (Figure 4.2). Only Præstø Fjord and Ringkøbing Fjord had data for all the years 2001-2016. Comparing across sites, Præstø Fjord had the highest angiosperm cumulative cover, followed by Guldborgsund and Stege Bugt/Nor. At the other end of the scale were Hjarbæk Fjord, Korsør

Nor, Nissum Fjord and Roskilde Fjord exhibiting relatively low angiosperm cover. The overall trend across all 17 sites showed an increasing tendency from less than 3 % angiosperm cumulative cover to around 6-8 % in the last five years. However, the first years (2001-2003) were dominated by many 'zero' observations (e.g. in Korsør Nor), which may have been incorrectly substituted in the data processing, i.e. we interpreted lack of observation as 'zero' while the possibility exists that lack of observation meant lack of recording even though the angiosperm was present.

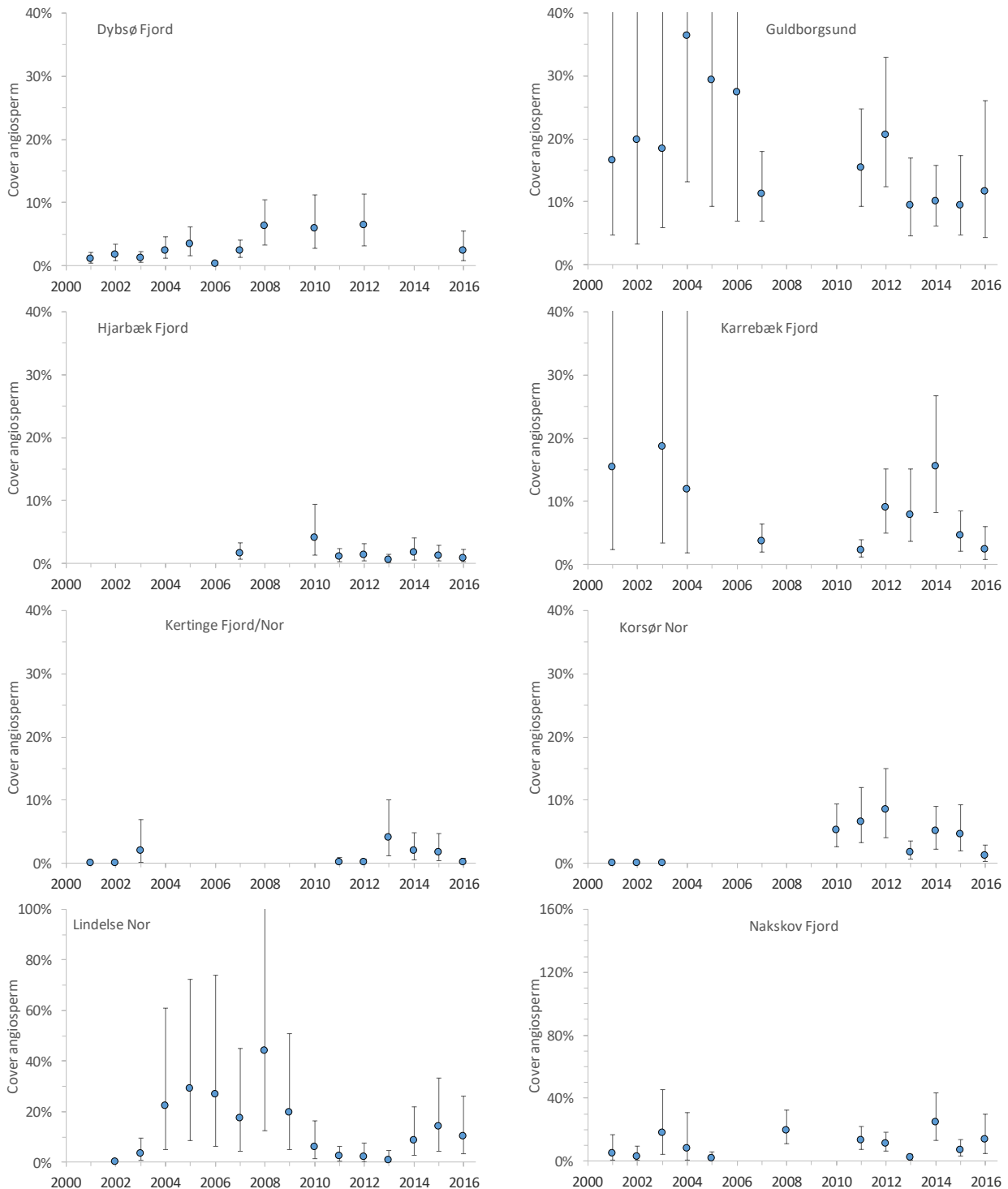


Figure 4.2. Annual means of angiosperm cumulative cover for the 17 investigated sites as well as the common trend across all 17 sites. Error bars show the 95 % confidence interval for the annual means. Note that the scaling varies among sites.

Figure 4.2. continues on next page

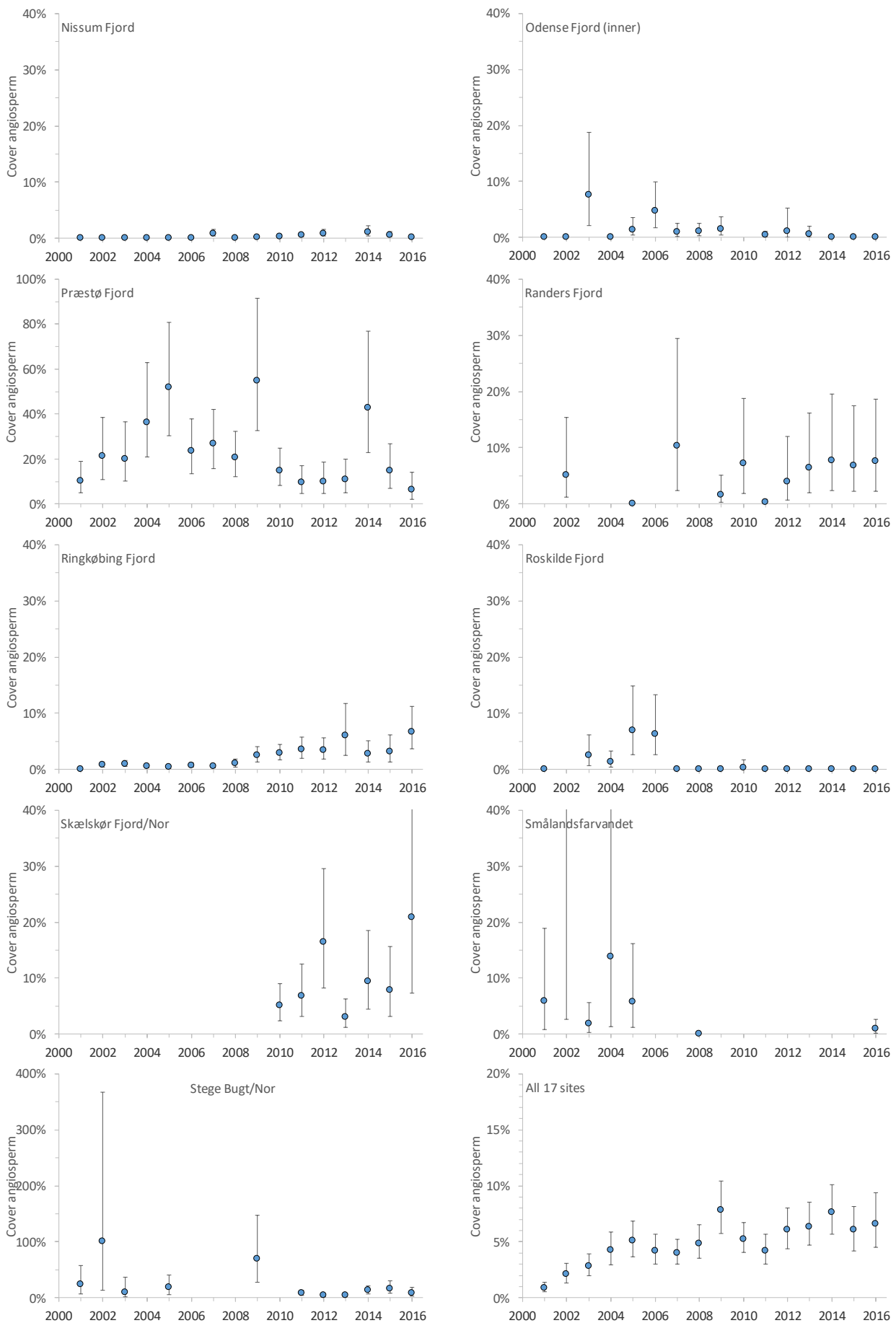


Figure 4.2. (continued) Annual means of angiosperm cumulative cover for the 17 investigated sites as well as the common trend across all 17 sites. Error bars show the 95 % confidence interval for the annual means. Note that the scaling varies among sites.

Similar to angiosperm cumulative cover, the four coastal sites with cumulative cover of charophytes also displayed a broad range of trends (Figure 4.3). There were many years with no charophyte cover recorded, and only Guldborgsund exhibited a trend without dominance of zero values. The few site-specific trends and the strong influence of zero observations suggest that the monitoring data set does not support the cover of charophytes as a suitable indicator of ecological status. This is partly because their distribution is limited to the more brackish coastal sites.

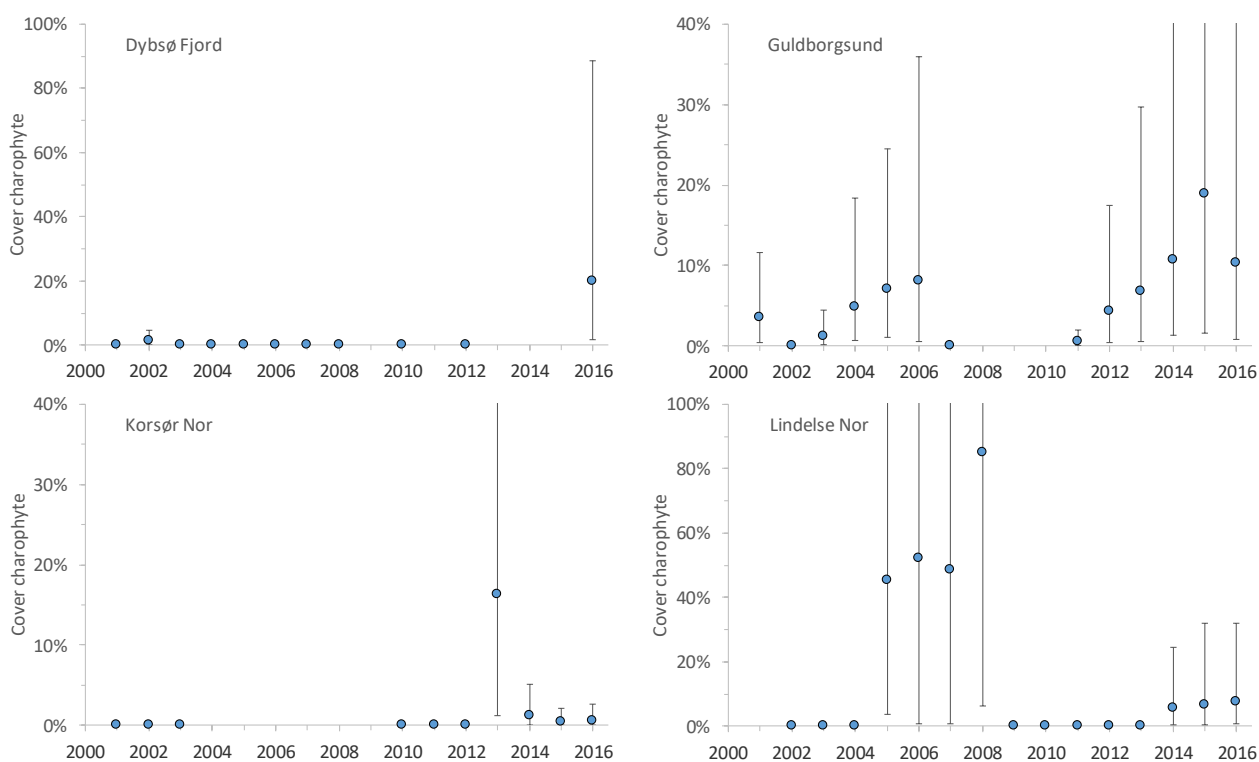


Figure 4.3. Annual means of charophyte cumulative cover for four investigated sites. Error bars show the 95 % confidence interval for the annual means. Note that the scaling varies among sites.

4.3 Relation to eutrophication pressure

Ecological indicators are expected to respond to one or several pressures. Therefore, we investigate if angiosperm depth limits and cumulative cover were linked to Secchi depth and nutrient levels at both spatial and temporal scales.

4.3.1 Responses at the spatial scale

Variations among coastal sites in angiosperm depth limits and cover were more strongly linked to the mean Secchi depth (Figure 4.4) than to mean nutrient levels. The relationships were particularly strong for depth limits. The maximum depth limit of angiosperms extended to approximately 90 % of the Secchi depth and the main depth limit was approximately 0.7 m shallower than the max depth limit. The cumulative cover of angiosperms was also related to Secchi depth, although there was more scatter in the relationship. This larger scatter could be due to relatively larger uncertainty on the site-specific means of cumulative cover, as indicated by the larger error bars for angiosperm cover, the many zero observations adding to this. Overall, the relationships document that angiosperms respond to changing light climate as expected.

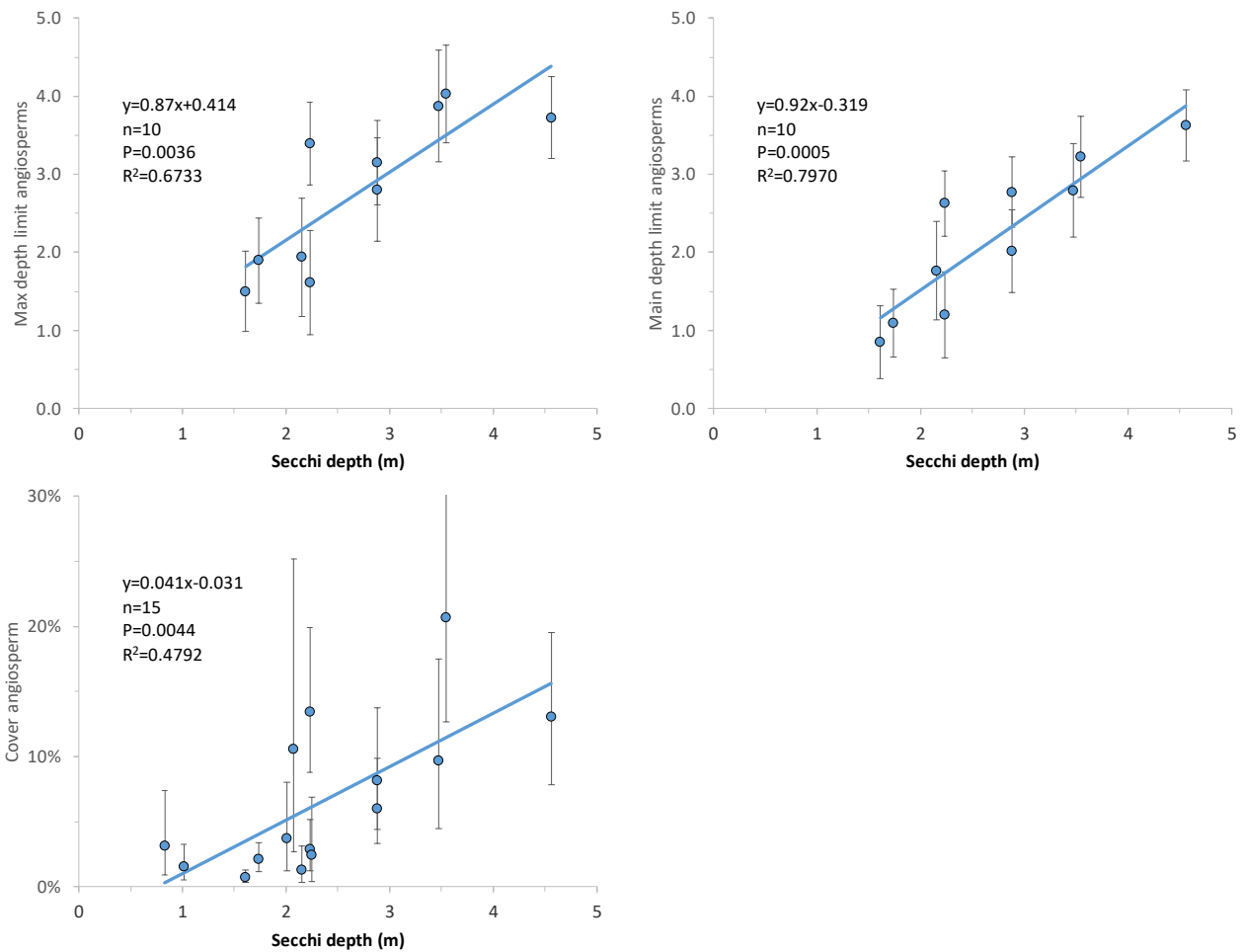


Figure 4.4. Relationships between site-specific means of max and main depth limits as well as cumulative cover of angiosperms at 2 m depth versus Secchi depth. Error bars show the 95 % confidence interval for the site-specific means.

4.3.2 Responses at the temporal scale

The annual means across all coastal sites were more strongly related to TN or TP changes over time than to changes in Secchi depth (2001-2016; *Figure 4.5*). However, the relationships between annual means were not significant for angiosperm depth limits and the significance for cumulative cover of angiosperms was mainly driven by a single year. The annual nutrient means ranged ~50 %, which is less than the spatial variation in Secchi depth ranging by a factor of 3 (*Figure 4.4*). The relatively low variability in annual means could explain the lack of significance in relating changes in angiosperm indicators to water quality changes over time.

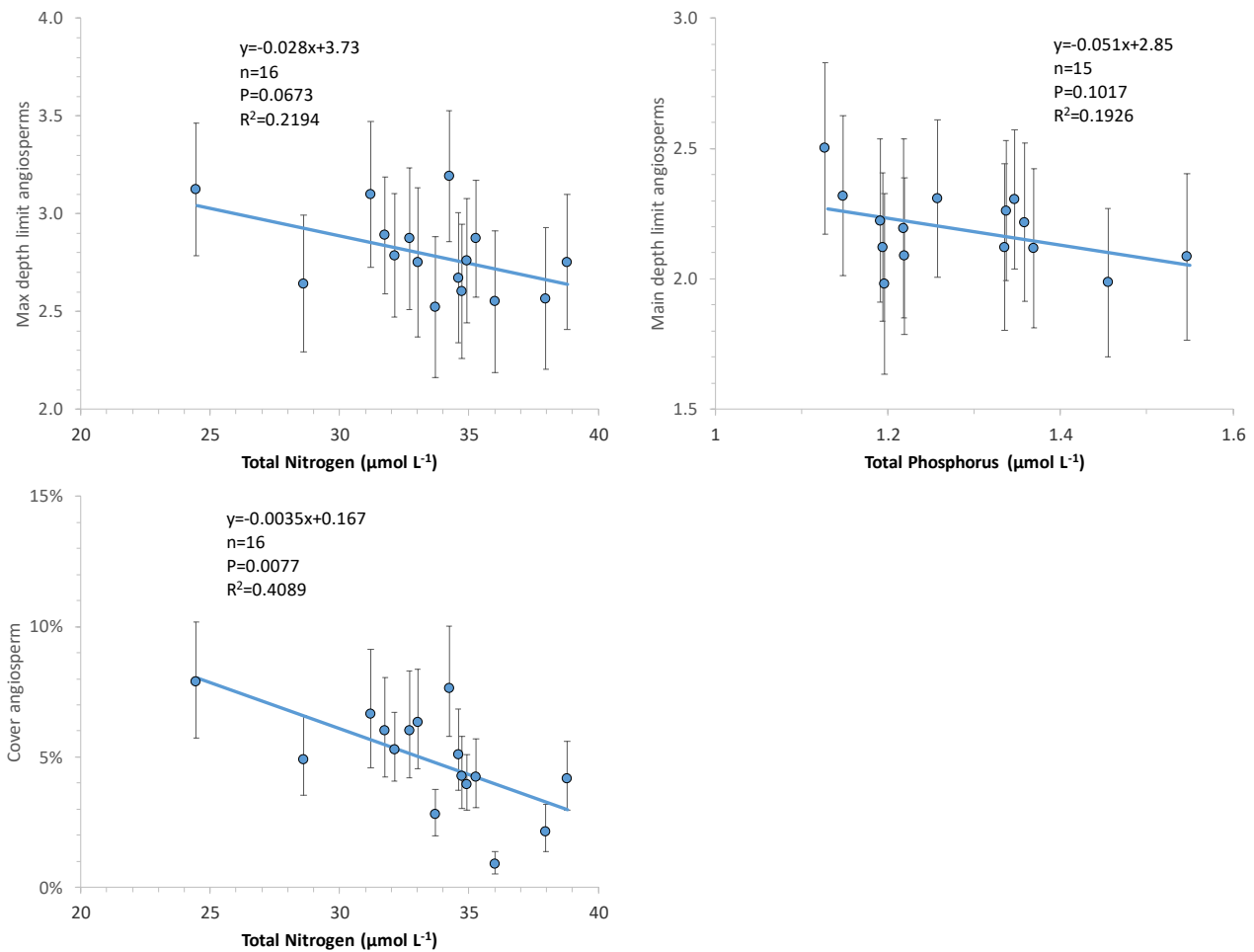
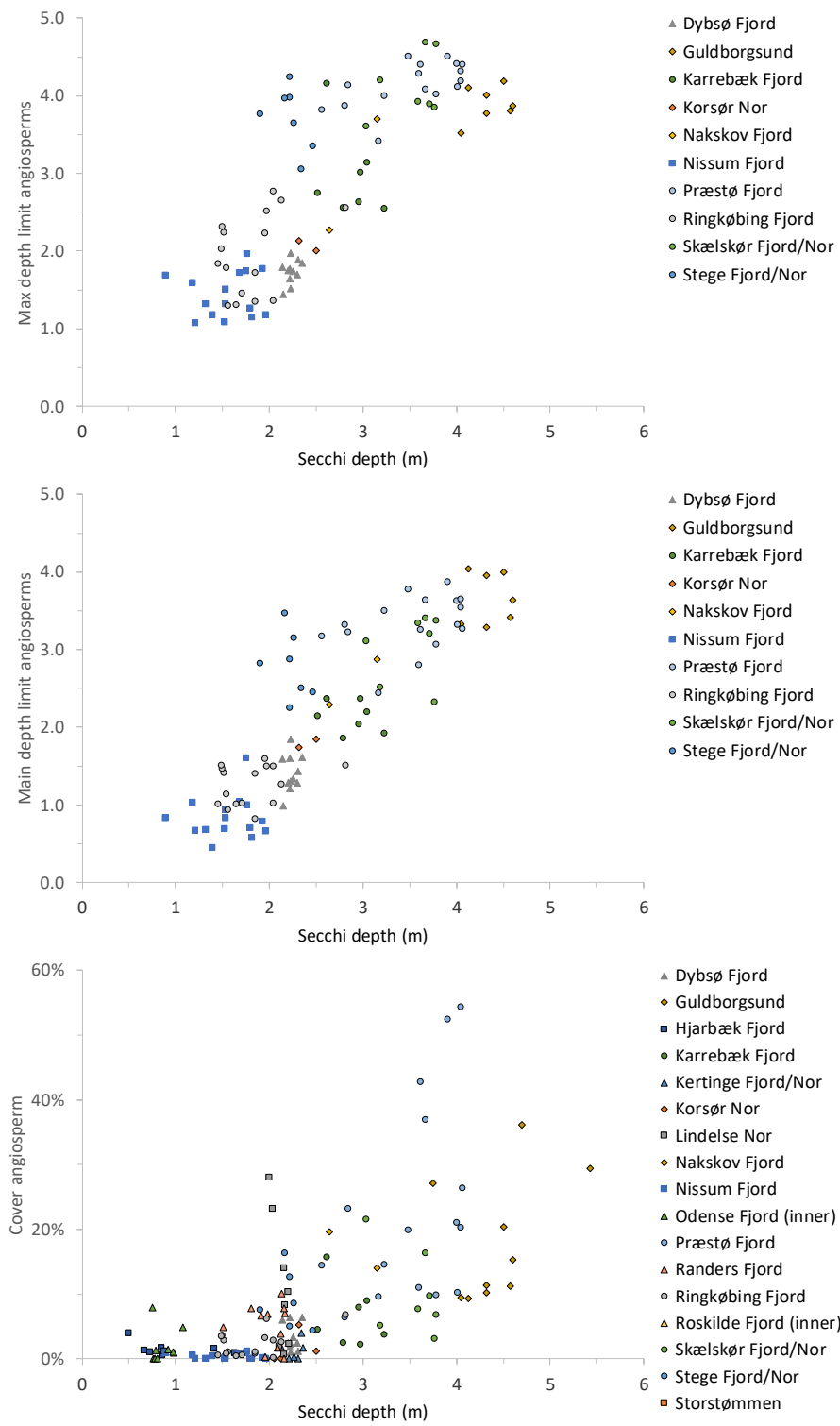


Figure 4.5. Relationships between annual means (2001-2016) of max and main depth limits as well as cumulative cover of angiosperms at 2 m depth versus nutrient levels. Error bars show the 95 % confidence interval for the annual means.

Considering all the site-specific annual means of angiosperm indicators versus Secchi depth produced expected patterns of increasing depth limits and cover with increasing Secchi depth, but these relationships were primarily driven by spatial differences rather than interannual variations (*Figure 4.6*). It is also noteworthy that the scatter was typically ~ 1 m for the site-specific annual depth limit means around the expected common relationship, which is of similar magnitude as the uncertainty of the site-specific annual means. This implies that a large part of the scatter (*Figure 4.6*) can be explained by the high uncertainty in the annual mean estimates, and that this scatter can be reduced if more depth limits were available to provide estimates that are more precise.

The relatively larger scatter for cumulative cover of angiosperms could also be explained by larger uncertainty of the site-specific annual means (*Figure 4.2*). Although there were considerably more cover observations than depth limits, the variability in cover observations is so large that it severely affects the confidence of the cumulative cover estimates. It is also possible that assessing the cover for individual species adds to the overall uncertainty of the aggregated cumulative cover observations, and that assessing the overall total cover of soft-bottom vegetation could reduce this uncertainty.

Figure 4.6. Relationships between site-specific annual means of max and main depth limits as well as cumulative cover of angiosperms at 2 m depth.



5 Indicator discussion

Observations of species-specific cover and depth limits of angiosperms (excluding *Zostera spp.*) and charophytes have been analysed using statistical models that account for the heterogeneous temporal and spatial sampling properties of the monitoring data. These observations can potentially produce indicators for angiosperms and charophytes that describe changes over time at regional and local levels.

Data on charophyte cover and depth distribution were too few to produce reliable indicator estimates, with just one area (Guldborgsund) having sufficient data for analysing trends in depth limits and just four areas having sufficient data for analysing trends in cover. Consequently, the monitoring data does not support the development of charophyte indicators for assessing ecological status of Danish coastal waters in general.

Indicators based on angiosperm cover and depth distribution data are more applicable for assessing ecological status, fulfilling the criteria for good indicator quality:

1. Angiosperms respond to the present light climate in a similar manner as eelgrass. Although there are many scientific studies documenting the causal linkages between angiosperms and light conditions, the scientific basis is dominated by seagrass studies.
2. Angiosperms typically grow in brackish and sheltered coastal ecosystems and may constitute the most important benthic vegetation in such systems. This study shows that angiosperms are found in coastal sites with salinity less than 15, although not common along open coastal stretches with low salinity such as Fakse Bugt and Hjelm Bugt. Hence, angiosperms (other than eelgrass) are important component of brackish coastal ecosystems.
3. Spatial variations in angiosperm cover and depth limits among coastal sites were clearly linked to prevailing light regimes. Our results suggest an almost proportional response in depth limits to changing Secchi depth, whereas the response in cumulative cover was weaker and more uncertain.
4. Ecological targets for angiosperm indicators have not been determined for Danish coastal waters. It is possible that such targets can be found from correlation analysis with eelgrass depth distributions, since reference conditions and class boundaries already exist for eelgrass depth limits. Also targets defined for depth limits of angiosperms in German boddens are relevant to consider (e.g. Selig et al. 2007).
5. Similar to eelgrass, it is difficult to assess the response time to changing pressures. Experiences from Nibe-Gjøl Bredning and Køge Bugt have shown that eelgrass responds to improved light conditions within a few years. However, the response to light conditions could be specific to the ecosystem. Only two coastal sites exhibited changes in angiosperm depth limits (Ringkøbing Fjord and Nissum Fjord). Although increasing depth limits appear to coincide with improving light conditions for some years

at these sites, the pattern is not consistent for the entire period (Figure 5.1). This implies that the recovery of angiosperms is more complex, involving potential time lags and other factors such as sediment suitability.

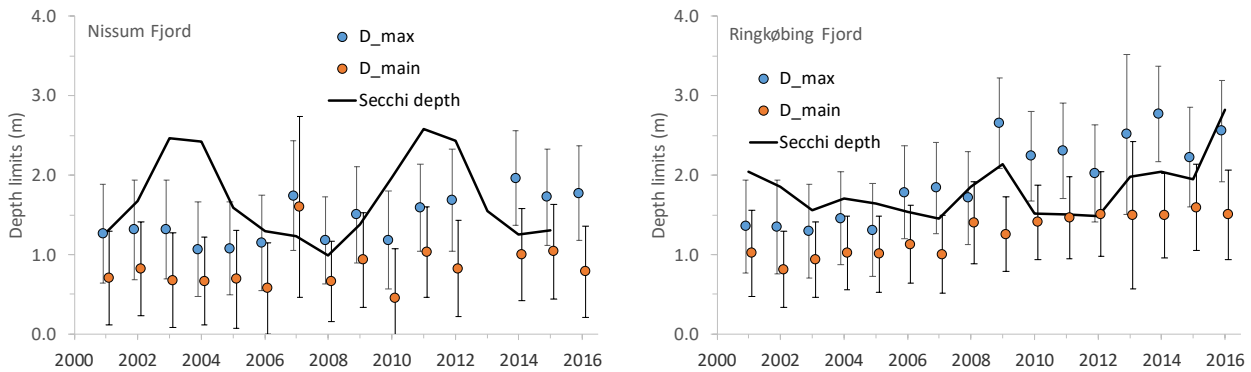


Figure 5.1. Trends in angiosperm depth limits and Secchi depth for the two sites exhibiting increasing depth limits.

6. Angiosperm depth limits and cumulative cover are both measurable, but depth limits provide more precise information than cover estimates. Given that annual means of depth limits were estimated from a few transects, it should be possible to obtain more precise indicators by monitoring more transects or focusing monitoring more specifically on determining the depth limit.
7. Angiosperm monitoring data are recorded together with eelgrass surveys and therefore, monitoring angiosperms is marginally inexpensive provided that eelgrass is already monitored. Thus, the additional cost of monitoring other angiosperm species than eelgrass is small.
8. Angiosperms have been monitored for several years and 16-year trends are available for many coastal sites already. Hence, there is an existing legacy from the marine monitoring programme to build upon.

Based on the above, we conclude that angiosperm depth limits are useful for assessing the ecological status in selected coastal ecosystems (brackish and sheltered), whereas cumulative cover is too variable to provide a good indicator. The monitoring data set does not offer a useful basis for developing charophyte indicators for assessing the ecological status of Danish coastal waters.

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