Validation of macroalgae indicators with observations from deeper depths

Sampling diver observations at deeper depths and estimation of macroalgae indicators

Scientific note from DCE – Danish Centre for Environment and Energy

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Data sheet

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Category: Scientific briefing

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Summary

Macroalgae indicators developed for the European Water Framework Directive can only be estimated for 25 out of 40 water bodies with monitoring data due to the lack of observations at deeper depth, where the macroalgae community is regulated by light. Analyses of side scan sonar data from Flensborg Fjord and Lillebælt have identified several locations, where such deeper macroalgae community data could be obtained. In this study, these locations were surveyed to produce macroalgae monitoring data following the technical guidelines, and the effect of including these additional data on the estimation of the two proposed macroalgae indicators was assessed. Depth ranges of the monitoring data were extended from around 14 m to 23 m, providing observations spanning depths from no light limitation to strong light limitation. Including these additional observations had a significant effect on the macroalgae indicators by improving both accuracy and precision of the indicator estimates. It is recommended to expand this exercise to other water bodies that lack deeper observations, expressing light limitation by identifying locations with potential suitable substrate at deeper depths and including these in the monitoring program.

Sammenfatning

Makroalgeindikatorer udviklet til brug for Vandrammedirektivet kan kun bestemmes for 25 ud af 40 vandområder med overvågningsdata. For de andre vandområder er der ikke data fra større dybder, hvor makroalgesamfundet bliver reguleret af lyset. Analyse af side scan sonar data fra Flensborg Fjord og Lillebælt har vist, at der potentielt findes dybere lokaliteter med mulighed for at opnå data om makroalgesamfundet. Makroalgesamfundet på disse lokaliteter er blevet overvåget i henhold til de tekniske anvisninger, og effekten af at inkludere disse ekstra data på bestemmelsen af makroalgeindikatorerne er undersøgt. De ekstra data udvidede overvågningsdybden fra 14 m til 23 m, hvilket repræsenterer dybdeforhold uden lysbegrænsning til stærk lysbegrænsning. Bestemmelsen af makroalgeindikatorerne blev mere korrekt og præcis ved at inkludere de ekstra overvågningsdata. Det anbefales at foretage den samme øvelse for andre vandområder, hvor der for nuværende ikke findes tilstrækkeligt dybe observationer med egnet substrat og lysbegrænsning. Såfremt sådanne dybere lokaliteter kan identificeres, bør de inkluderes i overvågningen.

1 Background

This technical note describes the outcome of the project 'Validering af makroalgeindikatorer ved dybere prøvetagning', which was carried out in the autumn of 2023. The project is financed by Miljøstyrelsen (Danish Environmental Protection Agency). Miljøstyrelsen has received and commented a draft version of the technical note.

DCE, the National Centre for Environment and Energy, has developed indicators for macroalgae that potentially can be used for assessing ecological status in relation to the European Water Framework Directive and ecological potential in relation to the European Habitat Directive. The indicators respond to changes in light conditions with both cumulative cover and the number of perennial species declining at greater depth (Carstensen 2020a). However, the proposed indicators can only be estimated in water bodies that have sufficiently deep observations (25 out of 40), and even for some of these, the indicator estimates are associated with considerable uncertainty (Carstensen 2020b). The main reason is the lack of macroalgae monitoring data for macroalgae at deeper depths, where light regulates the macroalgae coverage and community composition. If monitoring data for the macroalgae community at deeper depths can be acquired, then macroalgae indicators can be estimated for more water bodies and with greater confidence.

In a feasibility study, Dahl et al. (2023) examined side scan sonar data for identification of deeper locations in two water bodies (Flensborg Fjord, ydre and Lillebælt, syd) with potential suitable substrate for macroalgae. A total of 23 locations were investigated with ROV to confirm the presence of suitable substrate and macroalgae at depths ranging from 11 to 22.5 m. The fieldwork with the ROV documented the presence of 12 species of macroalgae at these depths, but as the survey was carried out in April using an ROV rather than diving, the data could not be compared directly with existing NOVANA data. Therefore, it was recommended to monitor these sites following the technical guidelines (Høgslund et al. 2013). Following up on this recommendation, the current study collected and analyzed data from the identified locations with the aim of determining the usability of macroalgae data from these locations and their influence on the estimation of macroalgae indicators.

2 Materials and methods

In addition to the regular macroalgae monitoring, a survey was conducted in the Little Belt and Flensborg Fjord on 11-14 September, 2023, covering the 23 identified locations (Dahl et al. 2023). This survey was carried out according to the national guidelines (Høgslund et al. 2013). A total of 17 different macroalgae species were identified, and the presence of sea urchins was also recorded. Due to technical difficulties, the survey had to be postponed from late August to early September, even though this time is outside the seasonal window for macroalgae monitoring. However, it is believed that this two-week delay will have a marginal effect on the observations. The observations have been quality assured and uploaded to the national database, Vanda.

These additional data were extracted from Vanda together with the ordinary monitoring data (2013-2023, covering almost two 6-year assessment periods, i.e. 2013-2018 and 2019-2023) to estimate the macroalgae indicators (k_{bio}) for cumulative cover and the number of perennial species according to Carstensen (2020a). The additional data contributed approximately 9% and 38% of the observations for Flensborg Fjord, ydre and Lillebælt, syd, respectively, for the second assessment period (2019-2023) (Table 2.1). Importantly, the depth ranges of the observations were extended from 13.0 m to 20.9 m in Flensborg Fjord, ydre, and from 13.9 m to 22.6 m in Lillebælt, syd, by including the additional observations.

For comparison, the macroalgae indicators were calculated with and without the additional macroalgae observations. The potential improvement of the precision of the macroalgae indicators was assessed by comparing the standard errors of k_{bio} estimated with and without the additional macroalgae observations.

Table 2.1. Overview of data for analysing macroalgae indicators in the two water bodies with additional data.

Water body	Type	Depths (m)	# of transects	# of obs.
Flensborg Fjord, ydre (2013-2018)	T.23	0.23 – 13.60	5	296
Flensborg Fjord, ydre (2019-2023)	T.23	0.10 – 13.00	3	212
Flensborg Fjord, ydre (w. additional deep data) (2019-2023)	T.23	0.10 – 20.90	10	233
Lillebælt, syd (2013-2018)	T.23	0.30 – 13.10	2	156
Lillebælt, syd (2019-2023)	T.23	0.40 – 13.90	2	81
Lillebælt, syd (w. additional deep data) (2019-2023)	T.23	0.40 – 22.60	19	127

Estimates of k_{bio} and C_{max} were compared with the estimates provided in Carstensen (2020a) to investigate whether the parameter estimates were consistent with the overall pattern, linking k_{bio} with k_d and C_{max} with salinity.

3 Results and discussion

In this section, the additional observations are compared with the existing monitoring data, and results from estimating k_{bio} for cumulative cover and perennial species richness in Flensborg Fjord, ydre and Lillebælt, syd are presented.

3.1 Suitable substrate

The cover of suitable substrate ranged from the required 10% to 90% in Flensborg Fjord, ydre, and from 10% to 100% in Lillebælt, syd (Fig. 3.1). However, there were a few observations with suitable substrate less than 10%, which have been reported for further quality assurance. None of the additional new deep observations had suitable substrate less than 10%.

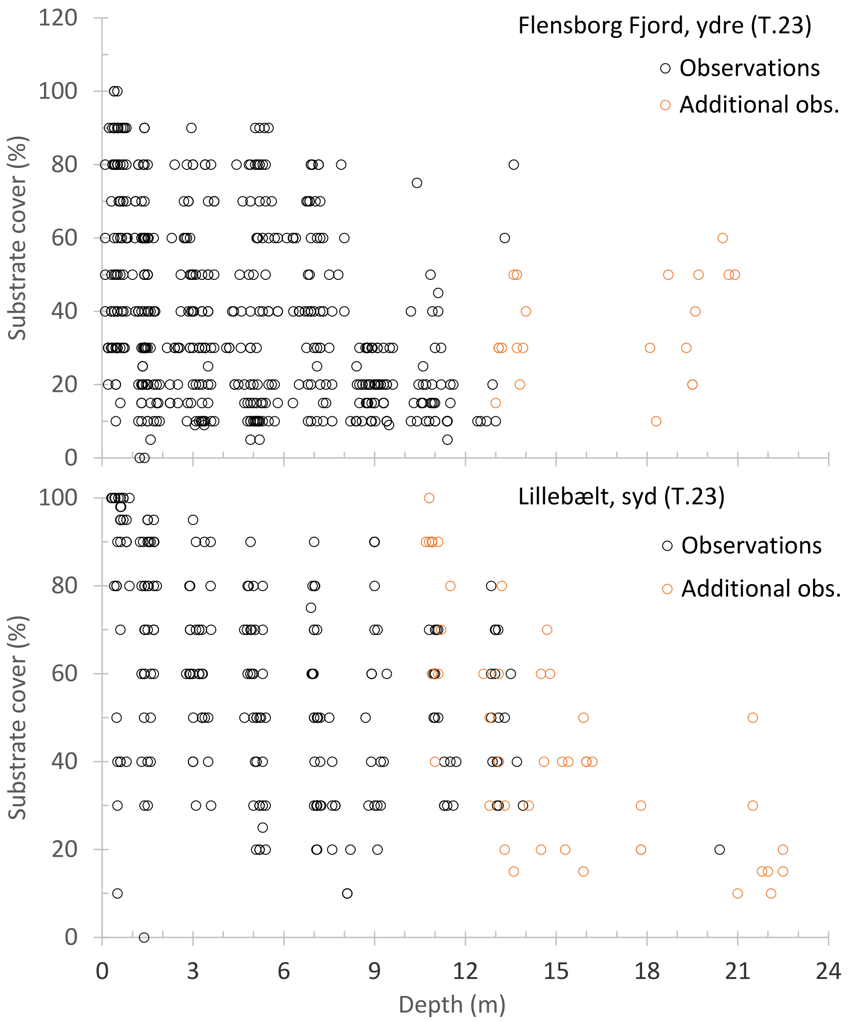


Figure 3.1. Cover of suitable substrate versus depth for the two investigated water bodies (2013-2023). Additional data are highlighted.

In Flensborg Fjord, ydre the cover of suitable substrate for the additional observations was similar to the NOVANA monitoring observations, whereas the deepest locations in Lillebælt, syd appeared to have lower cover of suitable substrate compared to the observations at shallower depths (Fig. 3.1). However, the cover of suitable substrate at intermediate depths (9-15 m) were similar for NOVANA and additional monitoring data.

3.2 Cumulative cover estimation

Flensborg Fjord, ydre:
Transects in the NOVANA monitoring program typically reach depths of around 13 m in Flensborg Fjord, ydre (Fig. 3.2). The additional survey extended the depth range to 21 m, which had a substantial impact on the parameter estimates for the cumulative cover model. For the two periods without the additional data C_{max}, estimates were around 150%, and k_{bio} estimates were 0.167 and 0.180 with standard errors of 0.012 and 0.015, respectively. Due to the limited depth range, the NOVANA data only covered an apparently small fraction of the light limited phase of the macroalgae community, which could affect the estimation of k_{bio}.

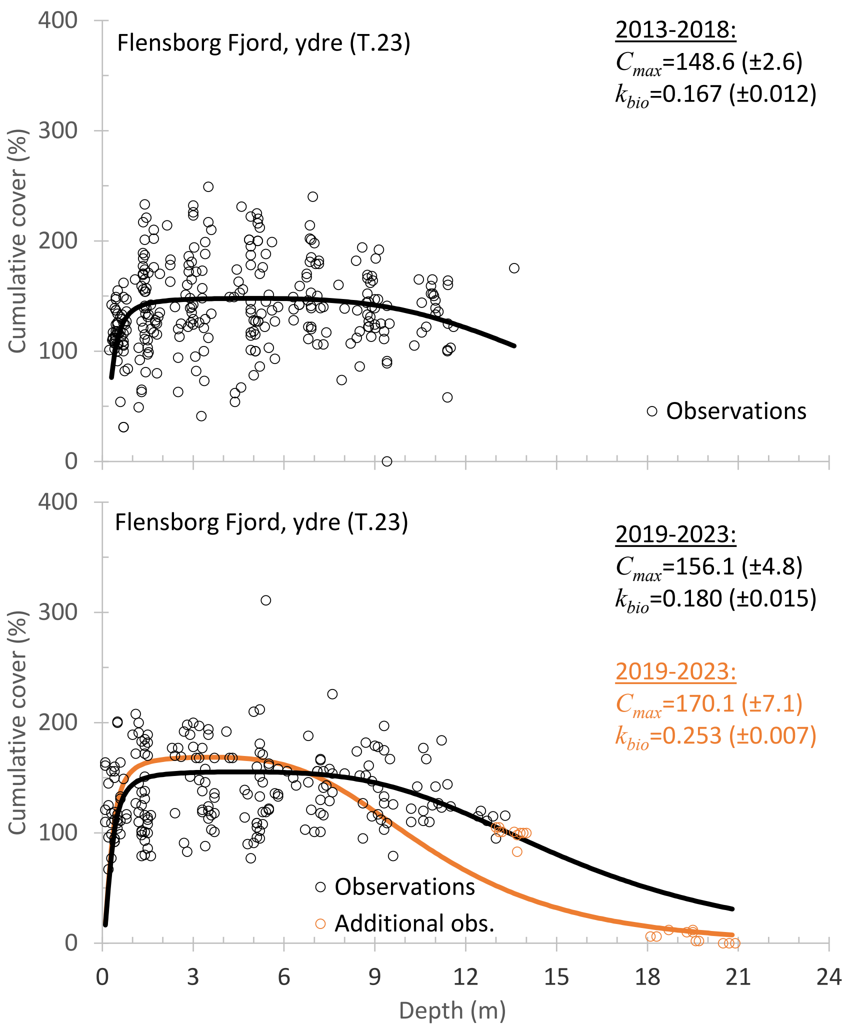
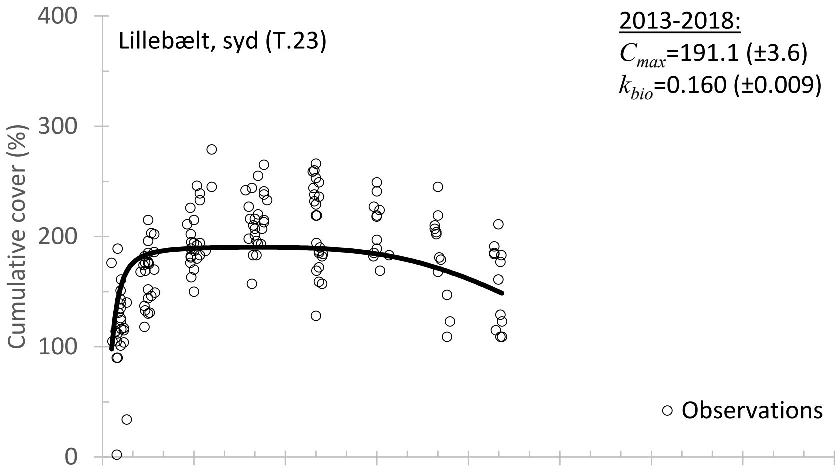


Figure 3.2. Cumulative cover across the depth gradient for the water body 'Flensborg Fjord, ydre' for two assessment periods. Additional data are highlighted, and their effect on parameter estimates are shown as inserts.

Including the additional observations from the 2023 survey had a large effect on the parameter estimates, most notably on k_{bio}, which was substantially higher. The estimate for C_{max} increased to 170%, and the estimate for k_{bio} increased to 0.253 with a standard error of 0.007, approximately half of the standard errors when the additional data were not included. As a rule of thumb, a halving of the standard error would normally require a 4-doubling of the number of observations, if these were sampled within the existing depth range (i.e. assuming that the standard error is proportional to $\sim 1 / \sqrt{n}$). Hence, additional data (9% extra) at deeper depths have a large impact on the precision of k_{bio}.

There was a gap in the depth gradient from 14 to 18 m, where the cumulative cover decreased from around 100% to almost no cover at all (Fig. 3.2). The model for cumulative cover did not capture this relatively large and rapid change and, most likely, it is not only caused by reduced light availability. Only two of the observations at deeper depths (>18 m) had recordings of sea urchins, so this could not explain the relatively low cumulative cover. Another possibility of the relatively low cumulative cover could be development of hypoxia/anoxia in the area. However, during the macroalgae survey, mats of sulfur bacteria were not observed and there were no apparent signs of a degraded macroalgae community due to oxygen deficiency (Rune Frederiksen, pers. comm.). Thus, there is no explicit explanation for the rapid decline in the cumulative cover between 14 and 18 m. However, it would be good if the gap in the depth gradient could be filled out by identifying appropriate locations with suitable substrate at depths between 14 and 18 m near the existing transects.



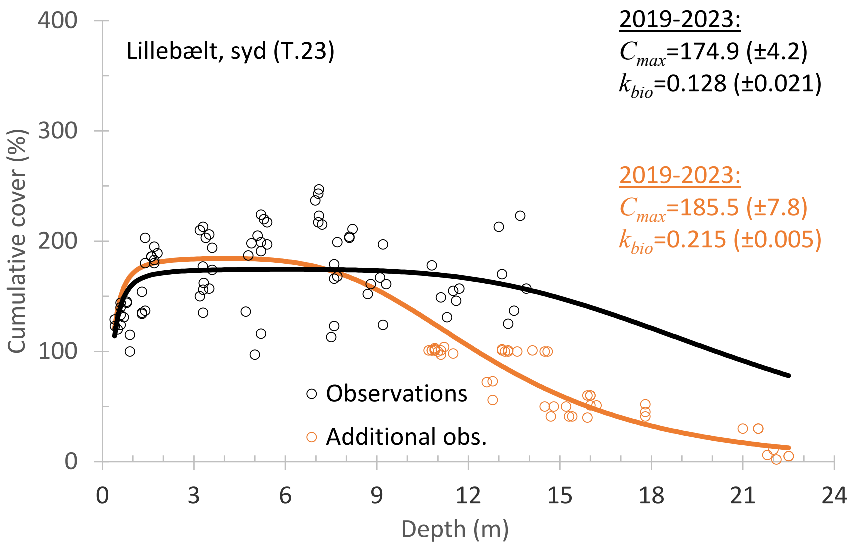


Figure 3.3. Cumulative cover across the depth gradient for the water body 'Lillebælt, syd' for two assessment periods. Additional data are highlighted, and their effects on parameter estimates are shown as inserts.

Lillebælt, syd:

Like Flensborg Fjord, transects in the NOVANA monitoring program typically reach depths up to 14 m, but the additional monitoring data extended the range to almost 23 m with adequate representation of all deeper depths (Fig. 3.3). The additional monitoring data did not change the estimate for C_{max} substantially, but the estimate for k_{bio} was substantially higher (0.215) compared to estimates without deeper observations (0.160 and 0.128 for the two periods). Due to the limited depth range of the NOVANA data, the estimates for k_{bio} were more uncertain (standard errors of 0.009 and 0.021) compared to the estimate that included the additional monitoring data (standard error of 0.005). This more precise estimate for k_{bio} highlights the importance of including observations with strong light limitation.

For the shared depth range between NOVANA and the additional monitoring data (between 10 and 14 m), the cumulative cover in 2023 was generally lower (Fig. 3.3). However, most of the monitoring in the second assessment period (2019-2024) was carried out by the same diver, so it is more likely that this could be due to 2023 being a year with generally poorer conditions for the overall macroalgae community. Note that there were no regular NOVANA data from 2023 for comparison in this study. In 2023, July and August were wet (high precipitation) and windy according to DMI, temperatures were high and Secchi depths relatively low (data not shown). Thus, it is possible that the relatively low cumulative cover in 2023 could be due to less favourable environmental conditions. This would also apply to the relatively low cumulative cover in Flensborg Fjord, ydre (Fig. 3.2).

Comparison with all water bodies:

The model estimates for C_{max} and k_{bio} compared well with the broad-scale relationships in Carstensen (2020a) (Fig. 3.4). Including data from the additional survey increased C_{max} estimates slightly, but they were still in line with the overall trend against salinity (Fig. 3.4a). Importantly, the estimates for k_{bio} were on the low side based on NOVANA observations only, but including the additional data increased the estimates to fit much better with the overall relationship between k_{bio} and k_d (Fig. 3.4b). Thus, including deeper observations improves both accuracy and precision of k_{bio} estimates.

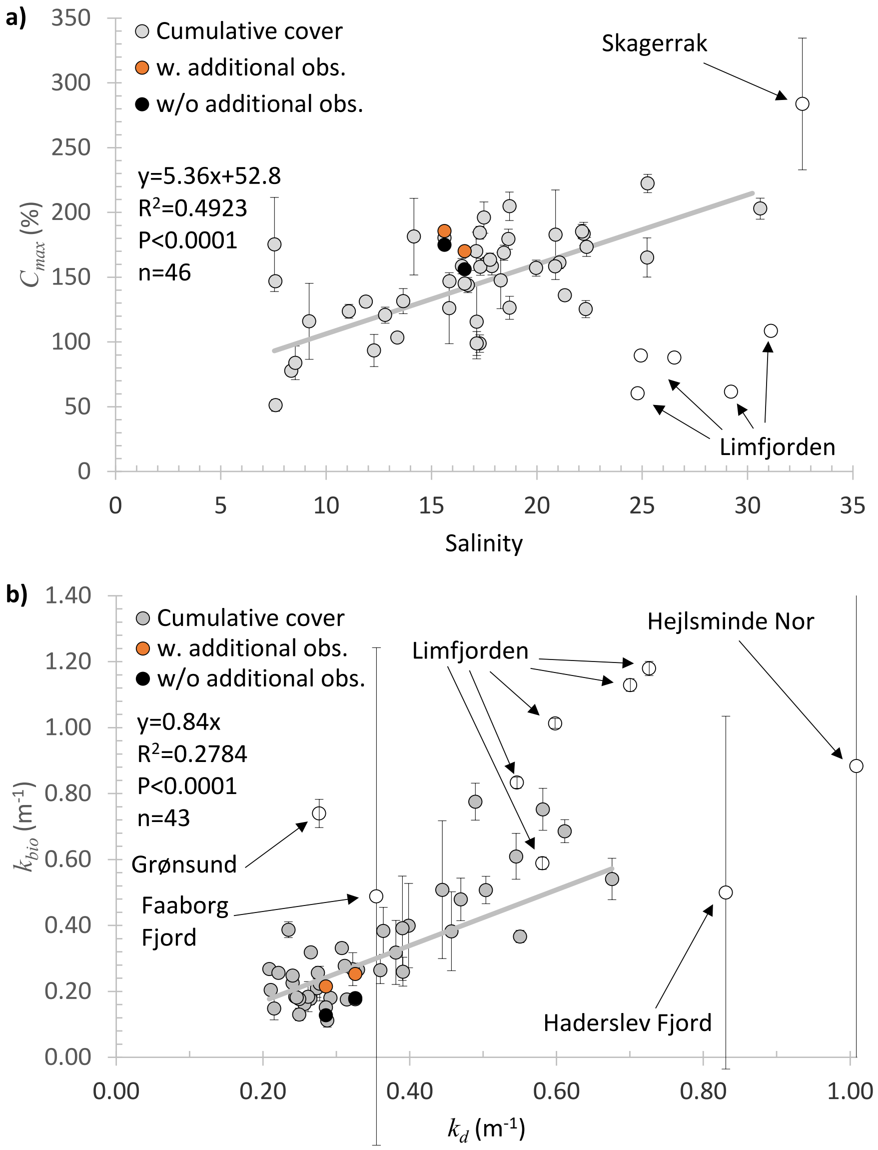


Figure 3.4. Estimates for cumulative cover of C_{max} versus salinity (a) and k_{bio} versus k_d (b) for different water bodies. Estimates from the second assessment period (2019-2023) with (orange) and without (black) the additional observations are overlaid the estimates (grey) from Carstensen (2020a).

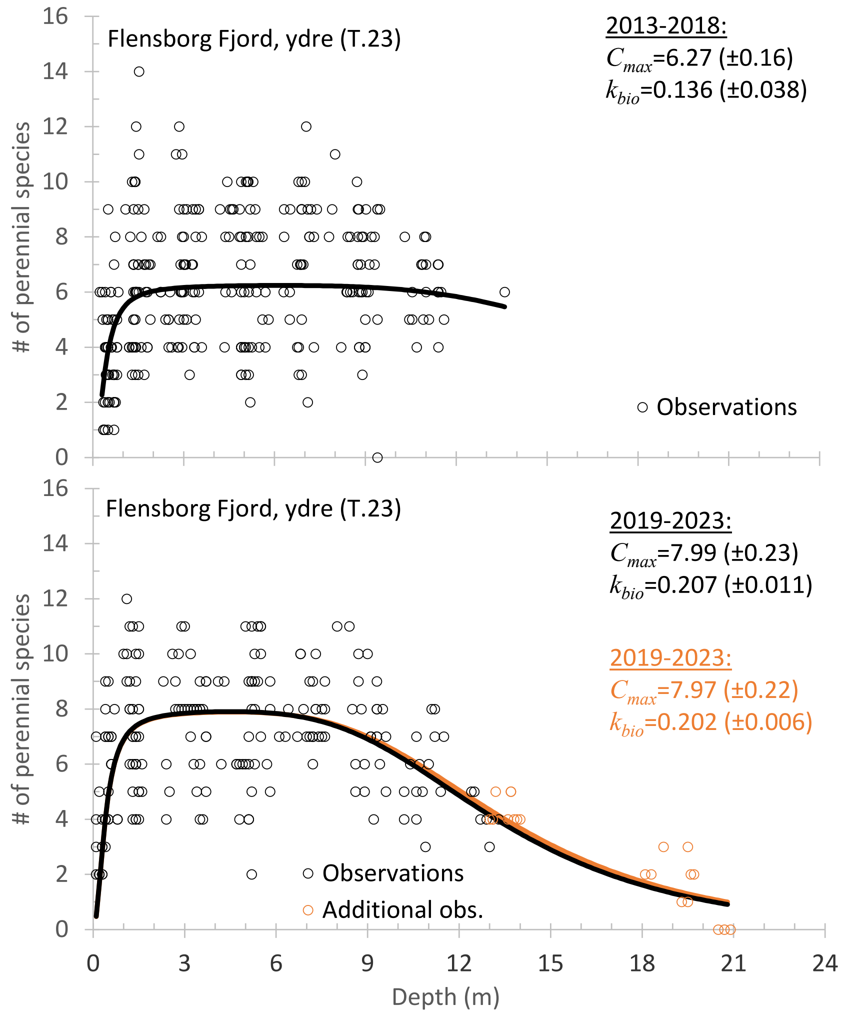


Figure 3.5. Perennial species richness across the depth gradient for the water body 'Flensborg Fjord, ydre' for two assessment periods. Additional data are highlighted, and their effect on parameter estimates are shown as inserts.

3.3 Perennial species richness estimation

Flensborg Fjord, ydre:

In Flensborg Fjord, ydre, k_{bio} estimates for the number of perennial species were relatively uncertain based on NOVANA observations only, particularly for the first assessment period, which did not have many observations expressing light limitation (Fig. 3.5). Noteably, the inclusion of the additional data reduced the standard error of the k_{bio} estimate by half, whereas the estimate itself only changed slightly from 0.207 to 0.202. There was no difference for C_{max} estimates during the second assessment period, when observations from the additional survey were included. Thus, the most important effect of additional data in Flensborg Fjord, ydre was the improved precision of k_{bio}.

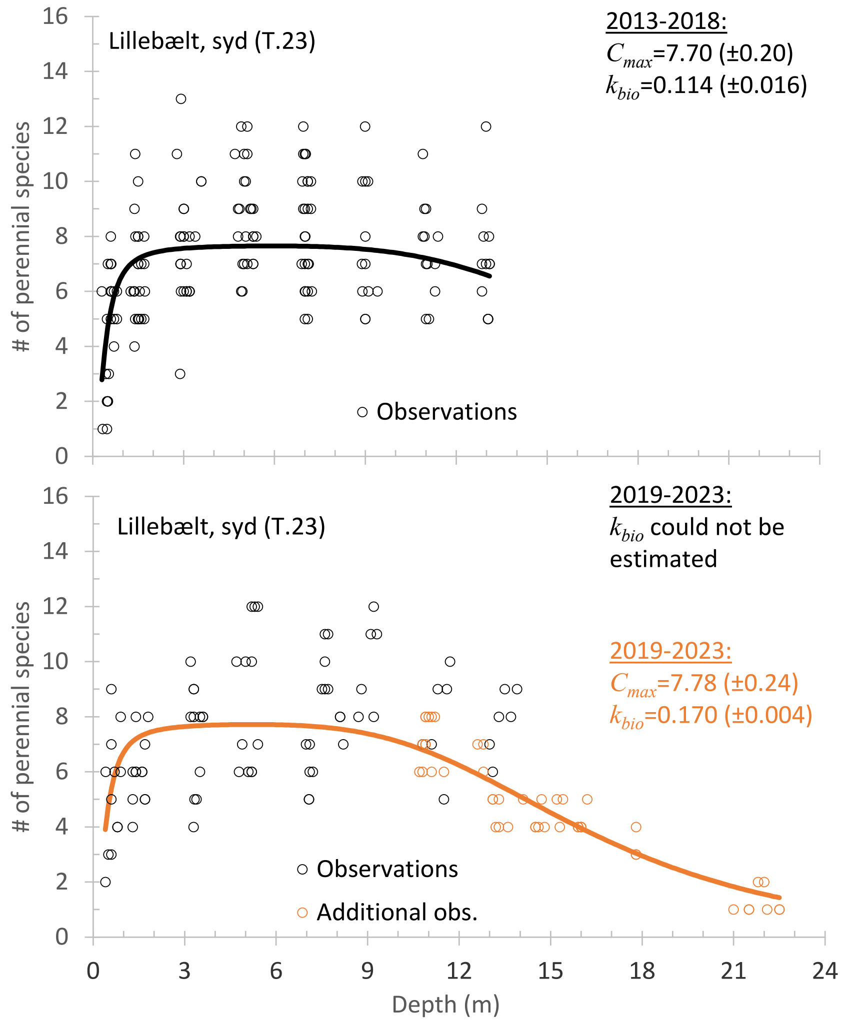


Figure 3.6 Perennial species richness across the depth gradient for the water body 'Flensborg Fjord, ydre' for two assessment periods. Additional data are highlighted, and their effect on parameter estimates are shown as inserts.

Lillebælt, syd:

In Lillebælt, syd, it was not possible to estimate the model for the second assessment period with NOVANA data only (Fig. 3.6). Including observations from the additional survey resulted in similar estimates of C_{max} for the two periods (7.7-7.8), whereas k_{bio} estimates were quite different. For the second assessment period with additional data, the estimate was $k_{bio} = 0.170$ (± 0.004) in comparison to $k_{bio} = 0.114$ (± 0.016) for the first assessment period. Hence, the inclusion of additional deeper observations reduced the standard error of k_{bio} by factor 4. In addition to improving indicator precision, the inclusion of additional data probably also improved the accuracy of k_{bio}.

Comparison with all water bodies:

In comparison to the broad-scale relationships in Carstensen (2020a), estimates of both C_{max} and k_{bio} compared well (Fig. 3.7). The effect of including additional data for estimating C_{max} and k_{bio} for number of perennial species could only be assessed for Flensborg Fjord, ydre, as the model did not converge with NOVANA data from the second assessment in Lillebælt, syd. The difference in parameter estimates for Flensborg Fjord, ydre was so small that there was no apparent improvement in accuracy of the k_{bio}

estimate. However, the k_{bio} estimate for the first assessment period in Lillebælt, syd was very low in comparison to the overall relationship with k_d, indicating that including deeper observations could also have a substantial effect on indicator accuracy.

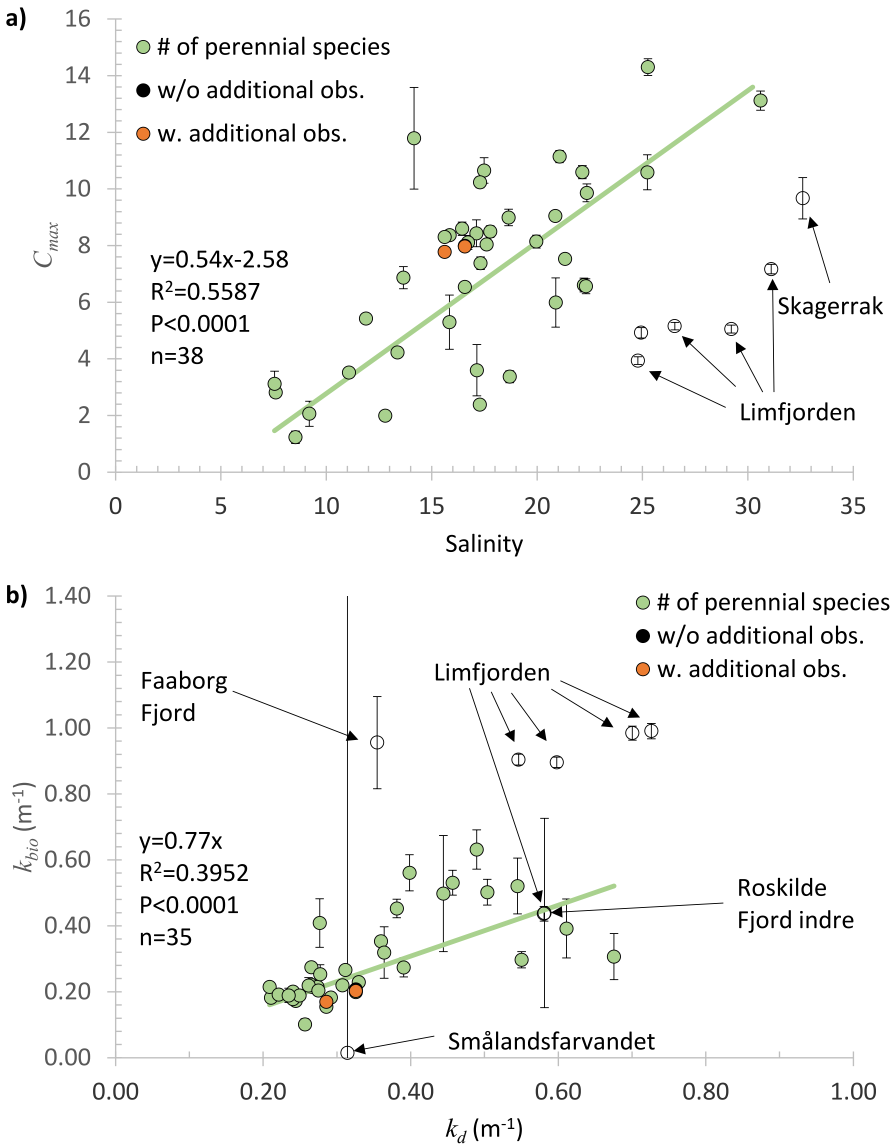


Figure 3.7 Estimates of k_{bio}r cumulative cover (a) and number of perennial species (b) versus light attenuation for different water bodies. Estimates from the second assessment period (2019-2023) with (orange) and without (black) the additional observations are overlaid the estimates from Carstensen (2020a).

4 Conclusion

Including additional macroalgae observations from depths with expressed light limitation had the following effects on the estimation of the two proposed macroalgae indicators:

- Estimates for k_{bio} (both cumulative cover and number of perennial species) were more accurate and compared better with the overall tendencies in relation to k_d.
- Estimates for k_{bio} (both cumulative cover and number of perennial species) were more precise, with standard errors generally reduced by factor 2 by including relatively few additional deeper data.
- Deeper observations reflecting strong light limitation are more important for accurate and precise estimates of the macroalgae indicators than the more abundant observations at depths representing light saturation.

5 Recommendations

Based on the analyses and conclusions, it is recommended:

- To identify water bodies lacking deeper data expressing light limitation, where estimation of k_{bio} could be improved or made possible.
- To investigate high-resolution side scan sonar data, if available, for these water bodies to identify locations with potential suitable substrate at depths with strong light limitation.
- To include these locations in the macroalgae monitoring program. This additional monitoring effort can be compensated by reducing monitoring efforts at shallower depths representing light saturation.

6 References

Carstensen J. 2020a. Macroalgae indicators for assessing ecological status in Danish WFD water bodies. Aarhus University, DCE – Danish Centre for Environment and Energy, 74 pp. Technical Report No. 170. https://dce2.au.dk/pub/TR170.pdf

Carstensen J. 2020b. Makroalgeindikatorer og deres anvendelse til VRD tilstandsvurdering. Notat fra DCE, 30. september 2020. https://dce.au.dk/udgivelser/notater/2020

Dahl, K., Göke, C., Carstensen, J., Gai, F., Petersen, P., Nielsen, S. 2023. Identifikation af dybe stenforekomster i Lillebælt og Flensborg Fjord. Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi, 55 s. - Teknisk rapport nr. 276. TR276.pdf (au.dk)

Høgslund S., Dahl, K., Krause-Jensen, D., Lundsteen, S., Rasmussen, M.B., Windelin A. 2013. Makroalger på kystnær hårdbund. Teknisk Anvisning (TA) nr. 12, DCE, Aarhus Universitet https://ecos.au.dk/fileadmin/ecos/Fagdatacentre/Marin/TA_M12_Makroalger_paa_kystnaer_haardbund_ver3.pdf