INTERCALIBRATION OF CHLOROPHYLL *A* BETWEEN DENMARK, NORWAY AND SWEDEN

Western Baltic (BC6), Kattegat (NEA8b) and Skagerrak (NEA8a, NEA9 and NEA10)

Technical Report from DCE – Danish Centre for Environment and Energy No. 76 2016

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Data sheet

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Abstract: This report documents the intercalibration of chlorophyll *a* between Denmark, Norway and Sweden in the shared types within the Baltic and Northeast Atlantic geographical intercalibration groups. A large dataset, combining monitoring data from the three countries, has been used to establish relationships between national metrics for chlorophyll *a*. Potential adjustment for biogeographical differences was deemed unnecessary. Based on these relationships, present national reference conditions and class boundaries for chlorophyll *a* were compared on a common scale. In most cases, differences were small and intercalibrated values were obtained by averaging translated national reference conditions and boundaries. In a few cases, intercalibrated values were modified to better reflect the land-sea gradient and to be consistent with OSPAR's values for the open Skagerrak. The intercalibrated values will be submitted by the national agencies in Denmark, Norway and Sweden to the European Commission decision on intercalibration.

Keywords: Water Framework Directive, eutrophication, phytoplankton, reference conditions, class boundaries, ecological indicators

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Preface

This report is the outcome of the Water Framework Directive intercalibration of chlorophyll *a* in coastal waters between Denmark, Norway and Sweden. Financial support has been provided by the Danish Nature Agency, the Norwegian Environment Agency and the Swedish Agency for Marine and Water Management. Intercalibration is a process carried out in geographical intercalibration groups for countries sharing the same type of water body, to ensure similar ecological status classification between countries. This report addresses intercalibration of five different coastal types in two geographical intercalibration groups (GIGs): the Baltic GIG and the northeast Atlantic GIG.

The method and results in this report have been presented to representatives of the agencies in Denmark, Norway and Sweden in November and December 2015, and the proposed intercalibration values for chlorophyll *a* will be submitted by the agencies to the European Commission decision on intercalibration. The method and results have also been presented to the coordinator for coastal intercalibration at the EC Joint Research Centre, who has endorsed the approach.

Summary

In this report reference conditions and class boundaries for high-good and good-moderate boundaries of phytoplankton biomass have been intercalibrated between Denmark, Norway and Sweden. Phytoplankton biomass was assessed using chlorophyll *a*, which is a measure of the photosynthetic active biomass in phytoplankton cells and provides a proxy measure of the phytoplankton biomass. The intercalibration approach followed the EC guidelines and was carried out separately for five common intercalibration types: BC6, NEA 8a, NEA 8b, NEA 9 and NEA 10. BC6 is located within the Baltic Geographical Intercalibration Group and the four other types are located in the North East Atlantic Geographical Intercalibration Group. The three countries use the same data acquisition for chlorophyll *a*, but assessment methods (metrics) differ.

A combined dataset with data from the three national monitoring programmes in Denmark, Norway and Sweden was established as the basis for the intercalibration. The three different national chlorophyll *a* metrics have been calculated for all water bodies using this combined dataset, allowing a direct comparison of the different assessment methods. The Danish metric was selected as the common metric, and both the Norwegian and Swedish metrics correlated strongly with the Danish metric. The chlorophyll *a* metrics were also strongly correlated to the total nitrogen concentration and no adjustments caused by potential biogeographical differences were needed.

Existing reference conditions and class boundaries for the three countries were translated to the common metric scale for each of the five types using the established relationships between national chlorophyll *a* metrics. In BC6 and NEA 8b differences in reference conditions and class boundaries between Denmark and Sweden were small, when these were compared with the common metric scale. In NEA 8a, 9 and 10, differences between Norway and Sweden were somewhat larger. Intercalibration of reference conditions and class boundaries was mainly done by averaging national boundaries translated to the common scale, but in NEA 8a, 9 and 10 some of the values were set to appropriate values, obeying the natural gradient from land towards the open sea and reference conditions and targets for good environmental status set by OSPAR for the open Skagerrak. Intercalibrated values for the common chlorophyll *a* metric were translated back to the national metric using established relationships. The final outcome of the intercalibration exercise was a set of intercalibrated chlorophyll *a* values for the five shared types in the Baltic GIG and NEA GIG, which will be submitted by the agencies in Denmark, Norway and Sweden to the European Commission decision on intercalibration.

Sammenfatning (in Danish)

Denne rapport omhandler interkalibreringen af referenceforhold og grænseværdier for høj-god og god-moderat tilstand af fytoplanktonbiomasse mellem Danmark, Norge og Sverige. Fytoplanktonbiomasse bestemmes som klorofyl *a*, som er en måling af den fotosyntetiske aktive biomasse i fytoplanktoncellerne og dermed en tilnærmet måling af biomassen. Interkalibreringen følger vejledningen fra EU Kommissionen og er gennemført for hver enkelt af de fem interkalibreringstyper: BC6, NEA 8a, NEA 8b, NEA 9 og NEA 10. BC6 tilhører interkalibreringsgruppen for Østersøen (Baltic GIG), hvorimod de fire andre interkalibreringstyper tilhører den nordøst Atlantiske interkalibreringsgruppe (NEA GIG). De tre lande benytter samme metodik for prøvetagning og måling af klorofyl *a*, men der er forskelle i de anvendte nationale tilstandsindikatorer baseret på klorofyl *a*.

Basis for interkalibreringen er et fælles datasæt, bestående af overvågningsdata fra Danmark, Norge og Sverige. Med baggrund i dette datasæt er de tre nationale tilstandsindikatorer udregnet for alle vandområder, hvilket gør det muligt direkte at sammenligne de nationale tilstandsindikatorer. Den danske tilstandsindikator er valgt som fælles sammenligningsgrundlag, og både den norske og svenske tilstandsindikator korrelerede kraftigt med den danske. Klorofyl *a* tilstandsindikatorerne var ligeledes tæt koblet til kvælstofkoncentrationen (TN). Der var ingen påviselige biogeografiske forskelle mellem landene, og der blev derfor ikke foretaget nogen justeringer mellem landene.

For hver af de fem interkalibringstyper er de eksisterende referenceforhold og grænseværdier i de tre land omsat til den fælles tilstandsindikator ud fra de etablerede relationer mellem de nationale klorofyl *a* indikatorer. I BC6 og NEA 8b var forskellene i referenceforhold og grænseværdier mellem Danmark og Sverige små, når disse blev omsat til den fælles tilstandsindikator. I NEA 8a, 9 og 10 var forskellen mellem Norge og Sverige lidt større. Interkalibrerede værdier for referenceforhold og grænseværdier er hovedsageligt bestemt som gennemsnittet af landenes værdier på skalaen for den fælles tilstandsindikator, men i NEA 8a, 9 og 10 var der behov for at tilpasse værdierne, således at de afspejlede en naturlig gradient fra land mod det åbne hav, og således at der var en sammenhæng til referenceforhold og miljømål fastsat af OSPAR for Skagerrak. De interkalibrerede værdier for den fælles klorofyl *a* tilstandsindikator er transformeret tilbage til de nationale tilstandsindikatorer ud fra de etablerede relationer. Hovedresultatet fra denne rapport er en liste af interkalibrerede klorofyl *a* værdier for de fem fælles typeområder i Baltic GIG og NEA GIG, som de respektive styrelser i Danmark, Norge og Sverige vil indmelde til Kommissionens beslutning om interkalibrering.

Sammendrag (in Norwegian)

Denne rapporten omhandler interkalibreringen av referanseforhold og klassegrenser for svært god-god og god-moderat tilstand av det biologiske kvalitetselementet planteplankton (biomasse) mellom Norge, Sverige og Danmark. Biomasse beregnes gjennom klorofyll *a*, som et mål på den aktive fotosyntetiske biomassen i algecellene og dermed et tilnærmet mål for biomassen. Rapporten følger instruksjonene fra Europakommisjonen, og er gjennomført for hver av de fem interkalibreringstypene BC 6, NEA 8a, NEA 8b, NEA 9 og NEA 10. BC 6 hører hjemme i interkalibreringsgruppen Østersjøen (Baltic GIG), mens de fire andre interkalibreringstypene tilhører den nordøst-Atlantiske interkalibreringsgruppen (NEA GIG). De tre landene benytter hovedsakelig den samme metodikken for prøvetaking og måling av klorofyll *a*, men det er nasjonale forskjeller på hvordan verdiene beregnes basert på klorofyll *a*.

Grunnlaget for denne interkalibreringen er et felles datasett, som består av overvåkingsdata fra Norge, Sverige og Danmark. Verdiene er beregnet for alle vannforekomster, noe som gjorde det mulig å direkte sammenligne resultater mellom landene. Den danske resultatverdien er valgt som felles grunnlag for sammenligning, og både den norske og svenske resultatverdi korrelerte sterkt med den danske. Klorofyll *a*-verdiene korrelerte også sterkt med total-N. Det var ingen beviselige biogeografiske forskjeller mellom landene, og ble derfor ikke foretatt noen justeringer mellom landene.

For hver av de fem interkalibringstypene er de eksisterende referanseforhold og grenseverdier i de tre landene endret til en felles indikator ut fra de etablerte relasjonene mellom de nasjonale klorofyll *a* klassegrenser. I BC 6 og NEA 8b var forskjellene i referansetilstand og grenseverdier mellom Danmark og Sverige små. For NEA 8a, 9 og 10 er forskjellen mellom Norge og Sverige litt større. Interkalibrerte verdier for referanseforhold og grenseverdier er i hovedsak gjennomsnittet av landenes verdier på skalaen til den felles tilstandsindikator, men for NEA 8a, 9 og 10 var det et behov for å justere verdiene slik at de gjenspeiler en naturlig gradient fra land til åpent hav, og slik at det var en link til referanseforhold og miljømål for Skagerrak som er satt av OSPAR. Grenseverdiene for fellesindikatoren er omregnet tilbake til de nasjonale tilstandsindikatorene.

Rapporten presenterer en liste over interkalibrerte klorofyll *a*-verdier for vanntypene BC 6, NEA 8a, 9 og 10 i Baltic GIG og NEA GIG, som Danmark, Norge og Sverige vil melde inn til Kommisjonens beslutning om interkalibrering.

Sammanfattning (in Swedish)

Denna rapport utgör resultat av interkalibrering mellan Danmark, Norge och Sverige av referensförhållanden och gränsvärden för hög-god och god-måttlig status av växtplankton biomassa. Fytoplankton biomassa bestäms som klorofyll *a*, som är ett mått på den fotosyntetiskt aktiva biomassan i fytoplankton cellerna och därmed ett ungefärligt mått på biomassan. Denna interkalibrering följer vägledningen från EU-kommissionen och har genomförs för vart och en av de fem interkalibreringstyperna: BC6, NEA 8a NEA 8b NEA 9 och NEA 10. BC6 hör hemma interkalibreringsgruppen Östersjön (Baltic GIG), medan de övriga fyra interkalibreringstyperna tillhör nordöstra Atlanten interkalibrering (NEA GIG). De tre länderna använder samma metod för provtagning och mätning av klorofyll *a*, men det finns skillnader i de nationella bedömningsgrunderna baserade på bl a parametern klorofyll *a* som ingår i bedömningsgrunden för phytoplankton i kustvatten.

Grunden för detta arbete är ett gemensam dataset bestående av övervakningsdata från Danmark, Norge och Sverige. Baserat på detta dataset är de tre nationella bedömningsgrunderna beräknade för parametern klorofyll *a* för alla vattenområden, vilket möjliggjort en direkt jämförelse. Den danska parametern är vald som gemensam grund för jämförelse, till vilken både den norska och svenska parametern korrelerar starkt. Klorofyll *a* är också nära kopplad till kvävekoncentration (TN). Det fanns inga uppenbara biogeografiska skillnader mellan länderna vilket föranlett några justeringar av ländernas data.

För var och en av de fem interkalibringstyperna har de befintliga referensförhållandena och gränsvärdena för klorofyll *a* omvandlats till en gemensam parameter baserat på nationellt etablerade samband. De interkalibrerade värdena är därefter ett resultatet från baktransformering från den gemensamt beräknade parametern och utifrån dessa samband. I BC6 och NEA 8b var skillnaderna i referensförhållanden och gränserna mellan Danmark och Sverige små när dessa transformerats till den gemensamma parametern. I NEA-8a, 9 och 10, var skillnaden mellan Norge och Sverige något större. Interkalibrerade värden för referensförhållanden och gränser bestäms huvudsakligen genom medelvärden utifrån var på skalan den gemensamma parametern hamnar, men för NEA 8a, 9 och 10 fanns ett behov av att justera medelvärdena så att interkalibrerade värden återspeglar en naturlig gradient från land till hav avpassat till referensförhållanden och miljömål inom OSPAR (Skagerrak). De viktigaste resultaten från denna rapport är listan över interkalibrerade referensvärden och gränsvärden för klorofyll *a* inom de fem gemensamma kustvattentyperna i Baltic GIG och NEA GIG. Värdena föreslås gemensamt av respektive myndigheter i Danmark, Norge och Sverige till kommissionens beslut om interkalibrering

1 Introduction

Phytoplankton are one of the biological quality elements of the Water Framework Directive constituting the basis for the overall ecological status assessment. According to Annex V of the Directive, the ecological status of phytoplankton in coastal and transitional waters should be based on assessing: 1) composition and abundance of phytoplankton taxa, 2) the average phytoplankton biomass, and 3) frequency and intensity of planktonic blooms.

Enhanced phytoplankton growth is the first obvious sign of nutrient over-enrichment, leading to an increased organic loading of aquatic systems, also termed eutrophication (Nixon 1995). The increase in phytoplankton growth is generally associated with an increase in phytoplankton biomass, except for systems where strong top-down control is exerted. However, due to losses by sedimentation and grazing, phytoplankton responses to nutrient enrichment are not strictly proportional, i.e. a doubling of the nutrient inputs is unlikely to cause a doubling of the phytoplankton biomass. For example, Markager et al. (2010) showed that a 10 % increase in nitrogen input only resulted in an expected 3 % increase in phytoplankton biomass. Effects of eutrophication are reduced water transparency, loss of benthic vegetation, and organic enrichment of the water column and sediments potentially leading to hypoxia. Due to the almost instant response in phytoplankton biomass to nutrient enrichment, phytoplankton biomass is a well-suited indicator of eutrophication disturbance.

Phytoplankton growth is mainly nitrogen limited in the coastal zone of the transition area from the Bornholm Basin to Skagerrak. Phosphorus limitation or co-limitation may occur during spring in coastal waters but this potential limitation on growth is alleviated during the summer period due to releases of phosphate from sediments and remineralisation in the water column, as well as relatively higher exchanges with open waters, compared to inputs from land, with N / P ratios in favour of nitrogen limitation.

Chlorophyll *a* is a measure of the photosynthetic active biomass in phytoplankton cells and provides a proxy measure of the phytoplankton biomass. However, the relative amount of chlorophyll *a* to phytoplankton biomass varies due to adaptation to changing levels of photosynthetic active radiation (PAR). The seasonal adaptation to changing incoming light levels is partly accounted for by a deeper distribution of the phytoplankton community in the water column during the summer period. Overall, chlorophyll *a* is considered a relatively robust proxy of phytoplankton biomass and relatively more precise than biovolumes / biomasses estimated from cell counts, frequently omitting picoplankton specimens.

In this report, present assessment methods for chlorophyll *a* in Denmark, Norway and Sweden are compared and intercalibrated, based on datasets from the three national monitoring programmes covering coastal water bodies within the types BC6 (Western Baltic Sea), NEA 8b (Kattegat), NEA 8a (inner coastal Skagerrak), NEA9 (Skagerrak fjords) and NEA 10 (open coastal Skagerrak). The first type belongs to the Baltic Geographical Intercalibration Group (Baltic GIG) and the remaining types belong to the North-East Atlantic Geographical Intercalibration Group (NEA GIG).

In general, the summer mean chlorophyll *a* concentration is being used as the indicator for phytoplankton biomass in the Baltic GIG , whereas the 90th percentile of the chlorophyll *a* distribution during the growing season (March to October is suggested) is being used in the NEA GIG. Both methods are included in the Commission Decision of 20 September 2013 of the intercalibration with EQR values representing class boundaries between high-good and good-moderate status for chlorophyll *a* in the intercalibration types BC8 and NEA1/26c (EC 2013). Intercalibration in BC6, NEA8a, NEA8b, NEA9 and NEA10 is yet uncompleted.

In the Baltic GIG, Denmark and Sweden share the common type BC6. In the NEA GIG, Denmark and Sweden share NEA 8b, and Norway and Sweden share NEA 8a, NEA9 and NEA10. Moreover, chlorophyll *a* is largely measured according to the same standard guidelines[1] in the three countries (same data acquisition), which should allow for intercalibration option 1 or 3 according to the EU intercalibration guidance. In this report, the possibility of intercalibration according to option 3 is examined (same data acquisition but different metrics).

Denmark is using surface chlorophyll *a* (1 m, mean for May-September). Sweden is using surface chlorophyll *a* (calculated as mean EQR value for June-August), where surface is integrated from 0-10 m (either hose sample or discrete samples mixed) in deeper water columns (> 12 m) and surface is 0.5 m at shallow stations (< 12 m). It is furthermore specified that the indicators can be adjusted, if the samples are unevenly distributed over the summer months, but no specific method for this adjustment is given. Norway is using the 90th percentile of chlorophyll *a* for the assessment period including observations from February to October. Observations for the indicator should represent the euphotic zone and should be taken at a depth of 5 m. Furthermore, in Denmark and Sweden the standard method for chlorophyll *a* extraction is to use ethanol, whereas in Norway acetone is used. Studies investigating the difference, provided by Norwegian experts, suggest that the difference is of minor importance. Further details on the national assessment methods can be found in Naturstyrelsen (2014), Miljødirektoratet (2013) and Naturvårdsverket (2007).

[1] Small differences may occur in the extraction (acetone/ethanol) and measurement (spectrophotometer/fluorometer).

2 Methods

The intercalibration of chlorophyll *a* in the five intercalibration types follows the guidelines laid out in CIS #14 (EC 2011), with the main task of the data analysis outlined in the flow diagram below (*Figure 2.1*). Each of the tasks is described in detail in the following subsections.

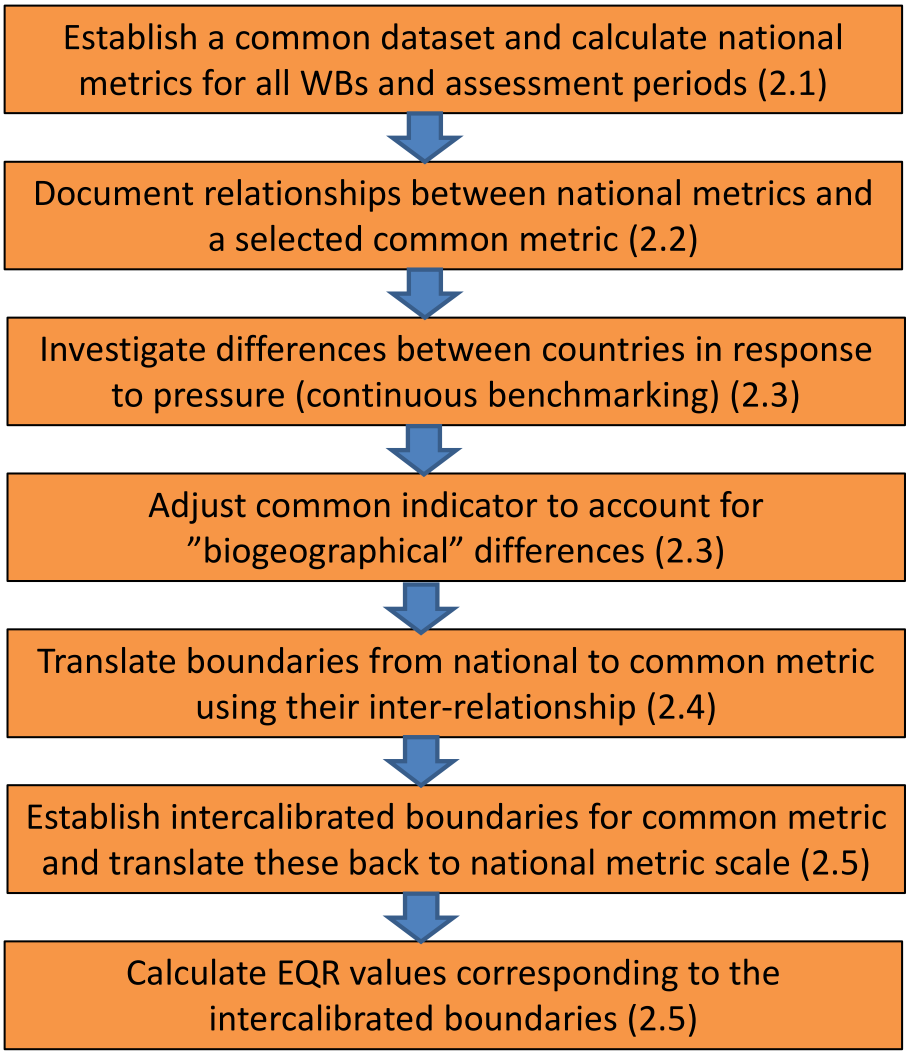


Figure 2.1. Flow diagram showing the different tasks carried out as part of the intercalibration exercise. Each task is described in detail in the subsection indicated in parentheses.

2.1 Establish common dataset

An essential task of the intercalibration exercise was to establish a common dataset that can be used for calculating the different national metrics for phytoplankton biomass, and derive supporting information to assess pressures and biogeographical differences between water bodies within the intercalibration types. For this purpose monitoring data from Denmark, Norway and Sweden have been extracted from national databases containing information on surface chlorophyll *a* (according to national definition, see below), salinity, temperature, total nitrogen (TN), total phosphorus (TP), Secchi depth, stratification and water depth. The variables in addition to chlorophyll *a* were used for comparing pressures and biogeographical differences among water bodies as part of the benchmarking in the intercalibration process. Stratification was determined as either stratified or mixed from measured density profiles, where the profile was deemed stratified if density difference exceeded 0.5 kg m^{-3}. TN and TP represented the main pressure on the coastal water bodies, whereas salinity, temperature, Secchi depth, stratification and water depth were used to characterize biogeographical differences among water bodies. Temperature affects phytoplankton growth rates, Secchi depth in combination with water depth is a proxy for potential light limitation, stratification and salinity can be used to characterize the potential benthic grazing effect (the diversity of benthic filter feeders is reduced in brackish water and the benthic grazing pressure is alleviated during stratified conditions).

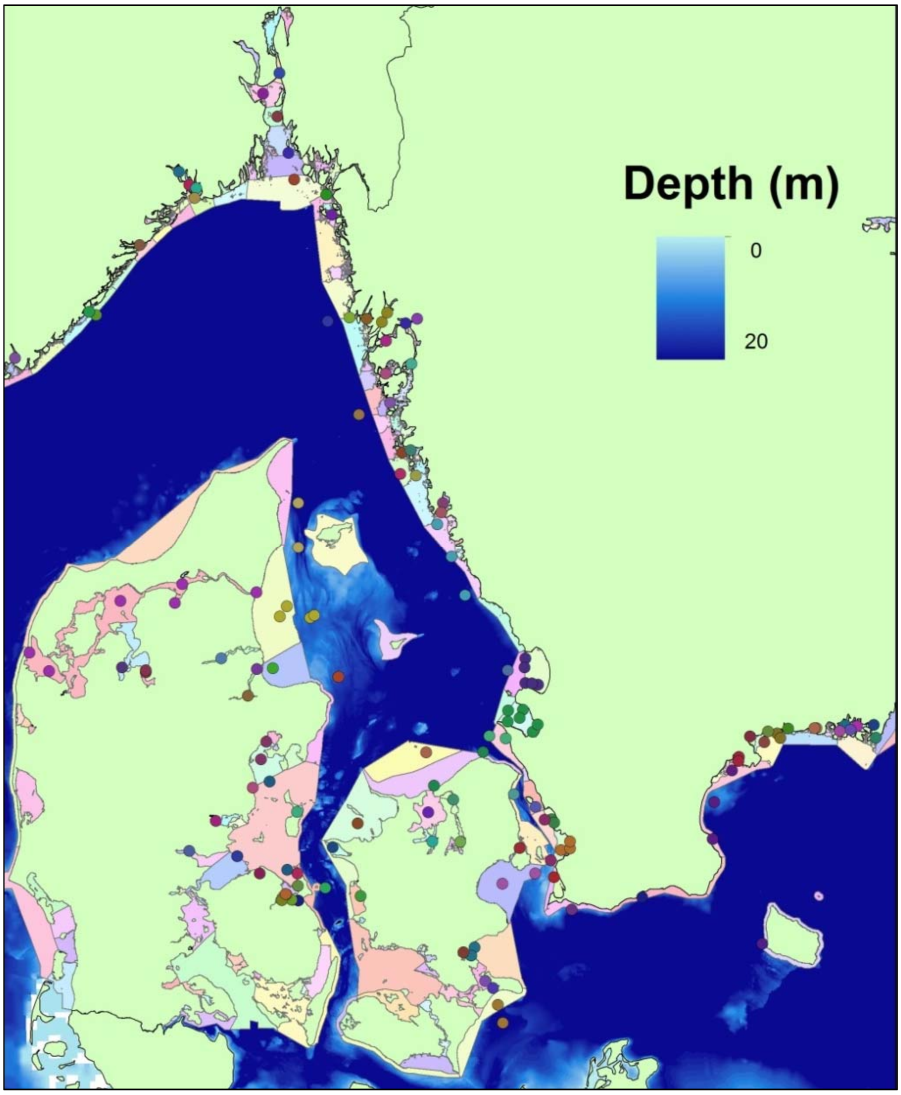


Figure 2.2. Monitoring stations used to characterise different water bodies within BC6, NEA 8a, 8b, 9 and 10. National WFD water bodies are shown with different coloured polygons in the coastal zone and stations representing different water bodies are also shown in different colours (note that colours are not matching between water bodies and stations).

The extracted monitoring data were restricted to the years from 1991 to 2014, which were divided into four distinct 6-year periods (1991-1996, 1997-2002, 2003-2008, and 2009-2014) to match the length of assessment periods according to the WFD. Splitting the time series into 6-year periods was also done to obtain more observations for the statistical analyses below. Monitoring data were associated with defined national water bodies depending on the location of the monitoring stations (*Figure 2.2*). The location of stations and water bodies had a relatively even distribution across the geographical limits of the intercalibration types as recommended in the guideline (EC 2011).

A number of stations were located outside the WFD baseline but were included to represent the nearest water body after consultation with the Danish Nature Agency, Norwegian Environment Agency and Swedish Agency for Marine and Water Management. For Denmark, these were stations 1009 and 403 representing 'Nordlige Kattegat, Ålbæk Bugt', station 409 representing 'Kattegat, Aalborg Bugt', station 415 representing 'Djursland Øst', station 6700053 representing 'Storebælt, NV', station 449 representing 'Hjelm Bugt', station 1877 representing 'Nordlige Øresund', station 1939 representing 'Kattegat, Nordsjælland', and station 1040050 representing 'Østersøen, Bornholm'. For Norway, station TH 1nm was representing 'Arendal - Tromøy'. For Sweden, these were stations VH3A representing 'V Hanöbuktens kustvatten', FALSTERBO representing 'V sydkustens kustvatten', ÖVF 5:2 HÖLLVIKEN representing 'Höllviken', KULLEN representing 'N Öresunds kustvatten', LAHOLM-3 (YG) representing 'Laholmsbuktens kustvatten', N14 FALKENBERG representing 'N m Hallands kustvatten', P2 representing 'Hjärteröfjorden', Å13 representing 'Sotefjorden', STRETUDDEN representing 'Yttre Brofjorden', and NORD-HÄLLSÖ representing 'Hällsöfjorden'. Furthermore, two stations were located on boundaries between water bodies and consequently used to represent both of these. For Denmark, station 6870 represented both 'Nordlige Lillebælt' and 'Århus Bugt syd, Samsø og Nordlige Bælthav'. For Sweden, station L9 LAHOLMSBUKTEN represented both 'Laholmsbuktens kustvatten' and 'Laholmsbukten'.

The entire dataset contained data from a total of 140 monitoring stations covering 100 coastal water bodies. The 100 water bodies were distributed among countries (43 in Denmark, 13 in Norway and 44 in Sweden) and among intercalibration types (24 in BC6, 7 in NEA 8a, 50 in NEA 8b, 11 in NEA 9 and 8 in NEA 10). Each water body could be represented with up to four assessment periods, and the combination of water bodies and assessment periods totalled 344. Within the five different intercalibration types, several national types were represented (*Table 2.1*). Some types were found only in one of the countries within a common intercalibration type. For example, in BC6, the Swedish type 8 (several fjords in Blekinge inner archipelago) and the Danish type M2 (Præstø Fjord, Stege Nor and Stege Bugt) are hydromorphological types specific to Sweden and Denmark, respectively. Similarly, in NEA 8b the Swedish type 1s (inner archipelago) and the Danish types representing various semi-enclosed water bodies (P2-4, M1-4, O3) are different and cannot be directly compared. Hence, for these two common types only the open coastal water bodies can be compared. Finally, the Danish water body 'København Havn' was not included as it represents a completely different system (heavily modified system).

Table 2.1. Coastal types according to national definitions in Denmark, Norway and Sweden used in the five common intercalibration types. National types not shared between countries are marked in red, and were not directly used for the intercalibration.

Common type	National type SE	National type DK	National type NO	Description
BC6	7, 8, 9	OW3b, OW3c, M2		Baltic Sea SW part (SE + DK)
NEA 8a	1n		2	Skagerrak inner coastal waters
NEA 8b	1s, 4, 5, 6, 25	OW2, P2, P3, P4, M1, M2, M4, O3		Kattegat and the Sound
NEA 9	2		3	Skagerrak fjords
NEA 10	3		1	Skagerrak open coastal waters

After excluding water bodies with a country-specific type, 56 water bodies remained for the intercalibration; of these were 10 in BC6, 7 in NEA 8a, 22 in NEA 8b, 9 in NEA 9 and 8 in NEA 10 (*Table 2.2*). Most of these water bodies had chlorophyll *a* observations in all four assessment periods, but the number of observations varied broadly among water bodies. The number of observations was low for some water bodies, but this would not imply that chlorophyll *a* status assessments were carried out, as the national metrics imposed constraints on the minimum number of observations.

Table 2.2. Water bodies included in the intercalibration for common types BC6, NEA 8a, 8b, 9 and 10. For each water body is listed the number of assessment periods covered with monitoring data as well as the number of chlorophyll *a* observations within specific months used for the national indicators.

Common type	Country	Water body	# assessment periods	# chlorophyll *a* observations May-Sep	Feb-Oct	Jun-Aug
BC6	DK	Fakse Bugt	3	300	504	183
BC6	DK	Hjelm Bugt	4	224	388	132
BC6	DK	Køge Bugt	4	435	752	263
BC6	DK	Østersøen, Bornholm	4	137	248	79
BC6	SE	Höllviken	3	79	168	49
BC6	SE	Sölvesborgsviken	4	33	43	11
BC6	SE	V Hanöbuktens kustvatten	4	137	202	68
BC6	SE	V sydkustens kustvatten	4	89	170	48
BC6	SE	Västra Blekinge skärgårds kustvatten	4	112	190	66
BC6	SE	Ö sydkustens kustvatten	1	15	27	9
NEA 8a	NO	Merdøfjorden - Havsøyfjorden	4	116	203	71
NEA 8a	NO	Midtre Oslofjord	4	56	96	39
NEA 8a	NO	Ytre Oslofjord	4	57	97	39
NEA 8a	NO	Østerfjorden	4	61	119	41
NEA 8a	SE	Kungshamn s skärgård	4	120	212	70
NEA 8a	SE	Stigfjorden	2	32	56	19
NEA 8a	SE	Yttre Brofjorden	4	120	210	70
NEA 8b	DK	Djursland Øst	4	57	102	33
NEA 8b	DK	Hevring Bugt	4	181	330	107
NEA 8b	DK	Kattegat, Aalborg Bugt	4	428	733	262
NEA 8b	DK	Kattegat, Nordsjælland	4	310	537	183
NEA 8b	DK	Kattegat, Nordsjælland >20 m	4	56	106	31
NEA 8b	DK	Nordlige Kattegat, Ålbæk Bugt	4	156	283	92
NEA 8b	DK	Nordlige Lillebælt	3	386	693	226
NEA 8b	DK	Nordlige Øresund	4	157	273	92
NEA 8b	DK	Sejerøbugt	4	139	267	80
NEA 8b	DK	Storebælt, NV	4	486	868	292

Table continues on next page

Common type	Country	Water body	# assessment periods	# chlorophyll *a* observations		
				May-Sep	Feb-Oct	Jun-Aug
Table 2.2 contiuned						
NEA 8b	DK	Århus Bugt syd, Samsø og Nordlige Bælthav	3	822	1470	485
NEA 8b	SE	Göteborgs s skärgårds kustvatten	1	1	1	0
NEA 8b	SE	Laholmsbukten	4	224	384	128
NEA 8b	SE	Laholmsbuktens kustvatten	4	112	194	63
NEA 8b	SE	Lommabukten	3	121	254	74
NEA 8b	SE	Lundåkrabukten	4	84	179	52
NEA 8b	SE	N m Hallands kustvatten	4	315	543	180
NEA 8b	SE	N m Öresunds kustvatten	4	137	238	85
NEA 8b	SE	N Öresunds kustvatten	4	85	177	52
NEA 8b	SE	Onsala kustvatten	4	121	217	70
NEA 8b	SE	S m Öresunds kustvatten	2	26	46	17
NEA 8b	SE	Skälderviken	4	188	316	116
NEA 9	NO	Breiangen-vest	4	55	96	39
NEA 9	NO	Hurum	4	56	96	39
NEA 9	NO	Håøyafjorden	3	61	103	36
NEA 9	NO	Langesundsfjorden	3	61	103	36
NEA 9	SE	Byfjorden	4	133	224	77
NEA 9	SE	Gullmarn centralbassäng	4	125	206	73
NEA 9	SE	Halsefjorden	4	124	217	73
NEA 9	SE	Havstensfjorden	4	134	227	78
NEA 9	SE	Koljö fjord	4	121	209	70
NEA 10	NO	Arendal - Tromøy	4	249	446	151
NEA 10	NO	Færder - Torbjørnskjær	4	59	99	39
NEA 10	NO	Langesundsbukta-indre	3	55	92	33
NEA 10	SE	Hjärteröfjorden	4	126	216	72
NEA 10	SE	Marstrandsfjorden	4	128	233	73
NEA 10	SE	N n Bohusläns skärgårds kustvatten	2	17	29	10
NEA 10	SE	S Kosterfjorden	4	121	212	70
NEA 10	SE	Sotefjorden	3	84	146	54

Using the chlorophyll *a* observations (*Table 2.2*), the three national metrics were calculated according to the national guidelines (Naturstyrelsen 2015; Miljødirektoratet 2013; Naturvårdsverket 2007; see also Carstensen et al. 2015). However, one modification was needed in order to calculate the Danish metric for the entire dataset. According to the Danish guidelines, the Danish metric requires at least eight chlorophyll *a* samples for calculating the yearly mean for the months May to September, and this requirement is largely fulfilled with the current Danish monitoring programme. However, in Norway and Sweden most monitoring stations are sampled monthly and consequently do not fulfil the requirement. Therefore, for Norway and Sweden the number of required samples per year was relaxed to four samples within May through September.

Potential differences between water bodies for other environmental variables were investigated by calculating means of salinity, temperature, total nitrogen (TN), total phosphorus (TP), and Secchi depth for all combinations of water bodies and assessment periods. These means were obtained from a general linear model (GLM) that in addition to a common seasonal variation had factors for years and stations nested within the combination of water body and assessment period (see Carstensen et al. 2006 for details). Moreover, the degree of stratification was investigated by calculating the average proportion of density profiles with a larger difference than 0.5 kg m^{-3} for each combination of water body and assessment period.

The combined dataset comprised 344 combinations of water body and assessment periods (including all types in *Table 2.1*) with information on the three national chlorophyll *a* metrics, annual means of salinity, temperature, TN, TP, and Secchi depth as well as the proportion of stratified profiles. This combined dataset constituted the basis for the intercalibration between the three countries.

2.2 Relationship between national and common metrics

It was agreed between the three countries to use the Danish metric as the common metric, since it included a larger seasonal window than the Swedish metric and because it was considered more robust and precise than the Norwegian metric. The use of the 90^{th} percentile has been criticised for being sensitive to outliers when the number of observations is low.

Relationships between the Danish metric versus the Norwegian and Swedish metrics were established using a log-log linear relationship with errors on both variables. The log-log linear relationship implies that the relationship on the original scale is a power relationship. The reason for employing a log-log linear relationship is that the uncertainty of the chlorophyll *a* metrics increases with the mean of the metric. Furthermore, a power relationship is forced through (0,0), implying that in theory both metrics should yield a zero value if chlorophyll *a* was completely absent. For the log-log linear relationship the slope estimate was tested to be 1, i.e. testing if the power relationship was linear (exponent equals 1 implies a proportional relationship).

2.3 Testing and adjusting for biogeographical differences

In this task the potential influence of other factors in addition to the main pressure, nutrient levels, was investigated. As described above, phytoplankton growth during summer is mainly limited by the availability of nitrogen. Therefore, it was investigated if there was a country-specific variation in addition to a general relationship between chlorophyll *a* and TN, which would account for biogeographical differences between countries sharing the same type.

This analysis was carried out as an ANCOVA, which is a combination of a linear regression (versus TN) and analysis of variance (country-specific factor), using the common chlorophyll *a* metric. A significant country-specific factor could indicate that biogeographical differences produce systematic differences in the chlorophyll *a* metrics. However, it is important that such a difference can be explained from the understanding of the phytoplankton ecology within the shared types.

If there, in addition to variations explained by TN, is a significant systematic difference between countries and this difference can be explained from the theory of phytoplankton ecology, the common metric should be adjusted for this systematic difference before the next steps of the intercalibration.

2.4 Translating boundaries to common metric scale

Denmark, Norway and Sweden have established reference conditions and boundary values for their national types and metrics with corresponding EQR values (*Table 2.3*, *Table 2.4*, and *Table 2.5*, respectively).

Table 2.3. Reference conditions, high-good (H-G) and good-moderate (G-M) boundaries for the Danish metric (chlorophyll *a* mean in May-Sep expressed as µg L^{-1}) for the different national types. Values are from Naturstyrelsen (2014). Water bodies with boundaries deviating from the national type are shown below their type in parentheses. Types not included in the intercalibration are listed in red.

Common type	National type	Ref.cond.	H-G	G-M
BC6	OW3b	1.0	1.3	1.7
	OW3c	1.0	1.3	1.7
	M2	1.3	1.6	2.1
NEA 8b	OW1	1.0	1.2	1.6
	(Ålbæk Bugt)	1.1	1.4	1.9
	OW2	1.0	1.2	1.6
	(N Øresund)	1.0	1.3	1.7
	(Storebælt NV)	1.1	1.4	1.9
	(Djursland Ø)	1.1	1.4	1.9
	M1	1.3	1.6	2.1
	(Inner Mariager Fjord)	3.6	4.5	6.0
	M2	1.3	1.6	2.1
	(Inner Roskilde Fjord)	2.2	2.7	3.6
	M3	2.2	2.7	3.6
	M4	2.2	2.7	3.6
	O3	4.2	5.3	7.0
	O4	4.2	5.3	7.0
	P1	1.3	1.6	2.1
	(Outer Mariager Fjord)	2.2	2.7	3.6
	P2	1.3	1.6	2.1
	P3	2.2	2.7	3.6
	(Kalundborg Fjord)	1.3	1.6	2.1
	(Århus Bugt)	1.3	1.6	2.1
	(Skive Fjord)	3.6	4.5	6.0
	P4	2.2	2.7	3.6
	Slusefjorde[1]	4.8	6.0	8.0
	(Hjarbæk Fjord)	5.4	6.8	9.0

[1]Nissum Fjord and Ringkøbing Fjord

Table 2.4. Reference conditions, high-good (H-G) and good-moderate (G-M) boundaries for the Norwegian metric (chlorophyll *a* 90th percentile in Feb-Oct expressed as µg L^{-1}) for the different national types. Values are from Miljødirektoratet (2013).

Common type	National type	Ref.cond.	H-G	G-M
NEA 8a	2	2.0	3.0	6.0
NEA 9	3	2.0	3.0	6.0
NEA 10	1	2.3	3.5	7.0

Table 2.5. Reference conditions, high-good (H-G) and good-moderate (G-M) boundaries for the Swedish metric (chlorophyll *a* mean in Jun-Aug expressed as µg L^{-1}) for the different national types. Values are from Naturvårdsverket (2007). For national type 8, the values are salinity-dependent with salinity ranges indicated in parentheses. Types not included in the intercalibration are listed in red.

Common type	National type	Ref.cond.	H-G	G-M
BC6	7	1.2	1.5	1.8
	8 (0-1)	15.7	20.2	25.2
	8 (1-2)	12.4	15.9	19.9
	8 (2-3)	9.5	12.2	15.2
	8 (3-4)	6.9	8.9	11.1
	8 (4-5)	4.8	6.1	7.6
	8 (5-6)	3.0	3.9	4.8
	8 (6-7)	1.7	2.1	2.7
	8 (>7)	1.2	1.5	1.8
	9	1.2	1.5	1.8
NEA 8b	1s	1.6	2.1	2.8
	4	1.0	1.2	1.5
	5	1.0	1.2	1.5
	6	0.9	1.1	1.5
	25	1.8	2.1	2.7
NEA 8a	1n	1.3	1.7	2.1
NEA 9	2	1.9	2.4	3.6
NEA 10	3	1.1	1.4	1.8

These national reference conditions and class boundaries were translated to the common metric using relationships between national metrics and the common metric, including potential adjustment for biogeographical differences. Using this approach, national reference conditions and class boundaries were translated to a common scale, enabling the comparison of values across countries.

2.5 Intercalibrating reference conditions and boundaries

The national reference conditions and class boundaries were compared on the common metric scale for each common type separately. This analysis was carried out bilaterally, i.e. between Denmark and Sweden for BC6 and NEA 8b and between Norway and Sweden for NEA 8a, 9 and 10. A further sub-division was employed for NEA 8b, since both Denmark and Sweden had reference values and class boundaries in the Sound (DK-type OW2 (N Øresund) and SE-type 6) deviating from the rest of NEA 8b.

A number of national types could not be intercalibrated as they were specific to their country (listed in red in *Table 2.3* and *Table 2.5*), and a few selected Danish water bodies had slightly elevated reference conditions and class boundaries relative to the overall type (marked in parentheses in *Table 2.3*). In these cases, the common intercalibrated reference conditions and class boundaries were scaled by the ratios of the national boundaries. For example in NEA 8b, the scaling factor for the reference condition in type M2 would be 1.3 µg L^{-1} (M2-specific reference condition) divided by 1.0 µg L^{-1} (general reference condition for OW1 and OW2) (*Table 2.3*). Intercalibrated reference conditions and class boundaries for the common metric were translated back to the national metrics for Norway and Sweden using the relationships between national chlorophyll *a* metrics and the common metric (Danish metric). The intercalibrated reference conditions and class boundaries for the national metrics were compared to the original national reference conditions and class boundaries.

Finally, EQR values for the intercalibrated class boundaries were calculated by dividing the intercalibrated reference condition with the intercalibrated class boundaries. These intercalibrated EQR values were compared with the original national EQR values.

3 Results and discussion

The entire combined dataset, partitioned into distinct combinations of water bodies and assessment periods, totalled 344 values, of which 203 were directly included in the intercalibration since they belonged to shared types. The Norwegian chlorophyll *a* metric was calculated for all these combinations, since the Norwegian method did not include any data restrictions (*Table 3.1*). The number of calculated metrics using the Danish and Swedish methods was lower, since both of these methods imposed data restrictions for their metric calculation.

Table 3.1. Number of chlorophyll *a* values (combinations of water bodies and assessment periods) calculated according to the Danish, Norwegian and Swedish metrics. Chlorophyll *a* metrics were also calculated for national types not included directly in the intercalibration (marked in red).

Common type	Included in intercalibration	# of DK metrics	# of NO metrics	# of SE metrics
BC6	Yes	27	35	30
	No	8	38	15
NEA 8b	Yes	67	80	72
	No	91	103	81
NEA 8a	Yes	21	26	22
NEA 9	Yes	32	34	30
NEA 10	Yes	26	28	25
Total		138	344	275

Environmental conditions were relatively similar between countries sharing the same common type (*Table 3.2*). In BC6 and NEA 8b, the Swedish water bodies were slightly more brackish, colder and less stratified than the Danish water bodies due to the stronger influence of outflow from the Baltic Proper. Another consequence of this was slightly higher TN concentrations in the Swedish water bodies. Salinities were also higher in Norwegian water bodies compared with Swedish water bodies in NEA 8a, 9 and 10 due to the stronger influence of North Sea and Atlantic water. The water bodies in these common types were mostly deep and almost permanently stratified. These three common types also reflected a land-to-sea gradient with lowest salinities in the fjords (NEA 9), increasing towards inner coastal (NEA 8a) and open coastal waters (NEA 10). This pattern was mirrored in Secchi depth and reversed in TN levels.

Table 3.2. Environmental conditions of water bodies in the five common types. Statistics are given as averages across all combinations of water bodies and assessment periods, including only those used for the intercalibration.

Common type	Country	Salinity	Temperature (°C)	Stratification (%)	Secchi depth (m)	TN (µmol L^{-1})	TP (µmol L^{-1})
BC6	DK	8.9	9.5	0.64	6.6	19.8	0.78
	SE	7.9	9.2	0.30	7.4	21.8	0.81
NEA 8b	DK	19.1	9.9	0.95	6.6	18.5	0.74
	SE	16.9	9.6	0.85	6.9	20.2	0.65
NEA 8a	NO	27.5	9.7	0.99	6.6	17.2	0.49
	SE	25.6	9.2	1.00	6.3	18.1	0.60
NEA 9	NO	26.4	9.7	1.00	5.5	17.9	0.51
	SE	23.0	9.8	1.00	4.7	22.8	0.73
NEA 10	NO	27.8	9.7	0.98	7.1	17.1	0.52
	SE	26.5	9.4	1.00	7.5	17.4	0.59

3.1 Comparison of national metrics with common metric

There was a strong and significant ($P < 0.0001$) correlation between the Swedish metric and the common metric (Danish metric) in both BC6 and NEA 8b (*Figure 3.1*). The parameters of the regression line suggested that the Danish metric produced slightly higher values than the Swedish metric, but both regression lines were close to the identity line (i.e. regression parameters equal 1). The standard deviation around the regression line was ± 11 % for BC6 and ± 14 % for NEA 8b in both dimensions. The Danish and Swedish water bodies and assessment periods were evenly distributed around the regression line, suggesting that no country-specific bias was introduced using different metrics. In general, the types not included in the intercalibration (national types not shared between countries) also appeared to follow the regression line, supporting that intercalibration results from the shared types could be extrapolated to types specific to countries.

In NEA 8a, 9 and 10, the relationships between the Swedish metric and the common metric were similarly significant ($P < 0.0001$) with parameter estimates close to the identity line. The standard deviation around the regression line was ± 12 % for NEA 8a, ± 10 % for NEA 9 and ± 12 % for NEA 10 in both dimensions. The Norwegian and Swedish water bodies were almost evenly distributed around the regression line.

The relationships between the Norwegian metric and the common metric were also significant ($P < 0.0001$), but the Norwegian indicator produced higher values that had to be scaled by factors between 0.30 and 0.49. The exponents of the regression lines suggest that there was an almost proportional relationship. There was more scatter around the regression lines with standard deviations at ± 27 % for NEA 8a, ± 18 % for NEA 9 and ± 28 % for NEA 10 in both dimensions. However, despite this increased uncertainty, Norwegian and Swedish water bodies and assessment periods were evenly scattered around the regression lines, suggesting that any potential bias in translating the Norwegian metric to the common metric was small.

In summary, there was a strong and significant correlation between the national metrics and the selected common metric that allow for translating values at the national metric scale to the common metric scale.

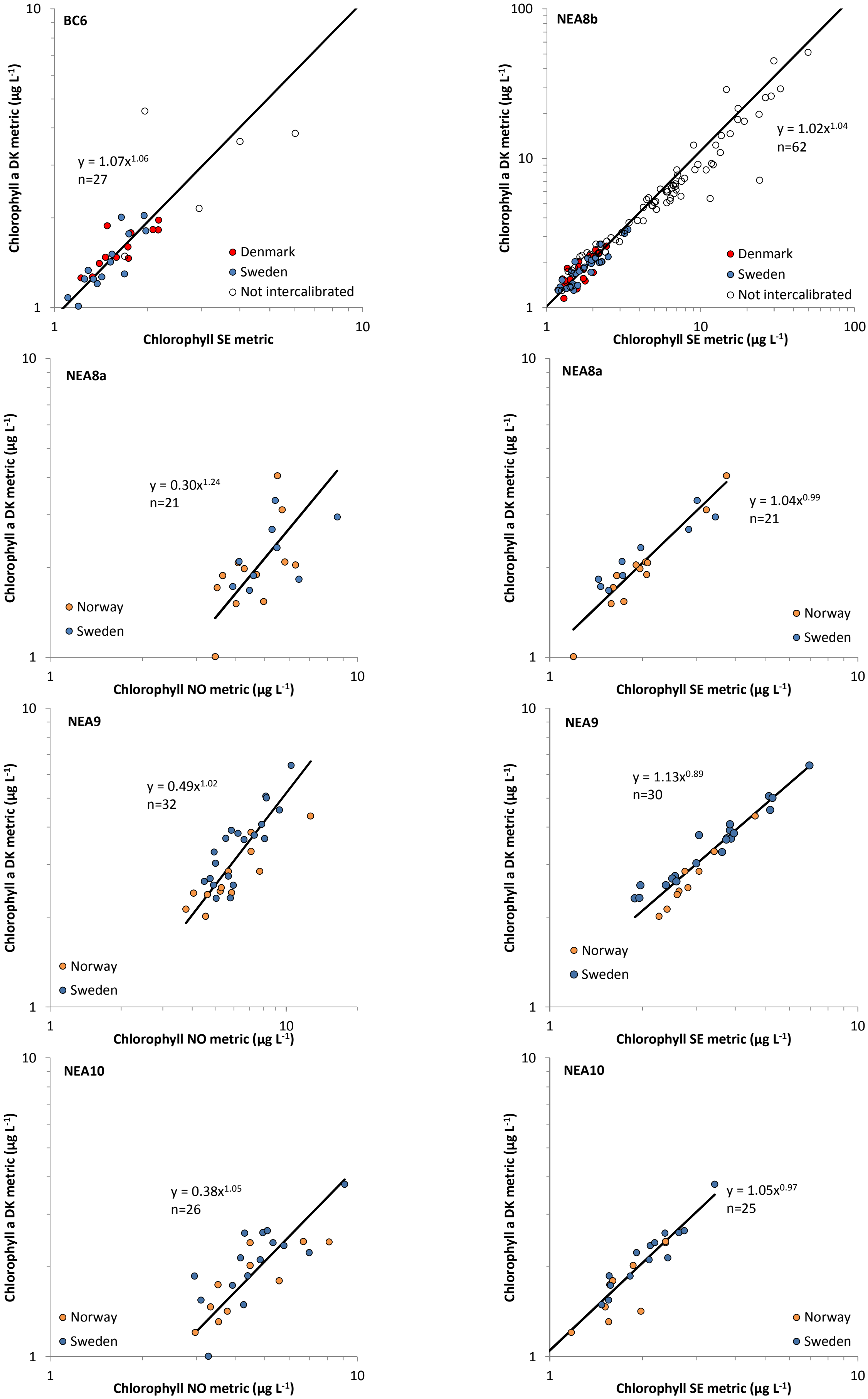


Figure 3.1. Relationships between the national metrics (Norway and Sweden) and the common metric (Denmark) for the five intercalibration types. The power relationship and the number of observations used for estimation are inserted with the regression line. Water bodies and assessment periods for the three countries are marked with different colours.

3.2 Continuous benchmarking

There was a positive correlation for the common metric with TN in all five types, although it was not significant for BC6 and NEA 8a (*Figure 3.2*). These two types had the smallest range in TN, which naturally affects the significance of such relationships.

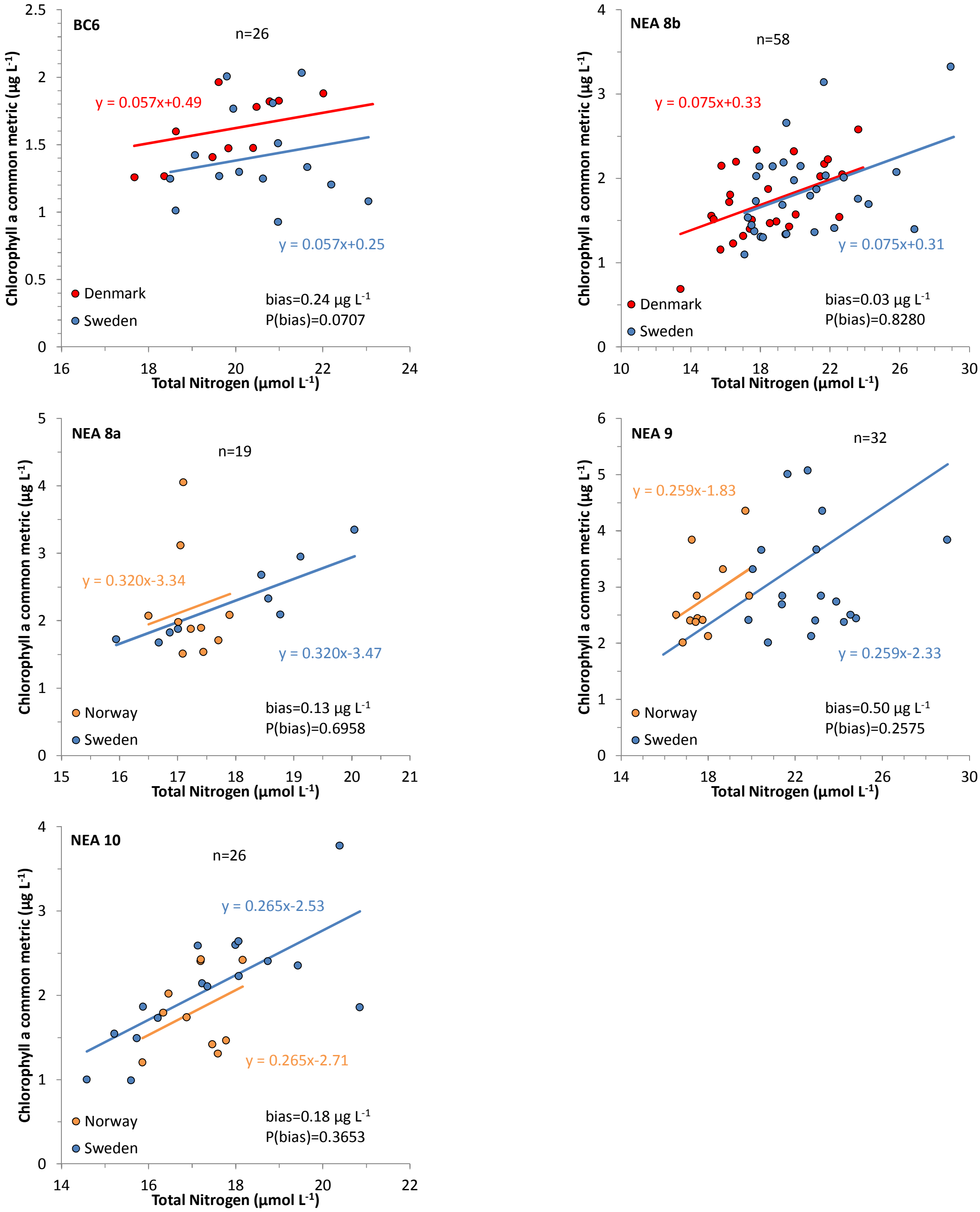


Figure 3.2. Relationships of the common metrics versus TN for water bodies and assessment periods within the five intercalibration types. Regressions and observations for each country are marked in different colours and regression statistics are inserted in each plot.

In BC6, the Danish water bodies were on average 0.24 µg L^{-1} higher than the Swedish water bodies in relation to TN. However, the difference was mainly in the TN level (19.8 and 21.8 µmol L^{-1} for Denmark and Sweden, respectively) rather than the common chlorophyll metric (1.60 and 1.41 µg L^{-1} for Denmark and Sweden, respectively). It is possible that this difference could be due to biogeographical differences, however, there are no obvious such differences between the Danish and Swedish shared types except for more frequent stratification at the Danish sites (*Table 3.2*). It is not known, if these differences in the stratification could significantly alter benthic grazing rates affecting the phytoplankton biomass. On the other hand, the Danish water bodies had higher salinity enabling more benthic filter feeders to settle in these habitats. A more likely and documented explanation is the composition of the TN. The bioavailability of the total nitrogen is low in the central Baltic Sea (Jørgensen et al. 2014) and since the Swedish water bodies are more strongly influenced by such water masses, a relatively lower chlorophyll *a* level to TN is expected for the Swedish sites (Carstensen & Henriksen 2009). Hence, the difference in the chlorophyll *a* response to TN between Denmark and Sweden in BC6 is most likely not due to biogeographical differences, but due to inadequacy of quantifying the labile portion of total nitrogen. Consequently, in BC6 there is no justification for adjusting chlorophyll *a* levels to account for biogeographical differences.

In NEA 8b, the effect of low nitrogen bioavailability in waters from the central Baltic Sea is strongly reduced due to stronger mixing with North Sea water. The difference in chlorophyll *a* response to TN between Denmark and Sweden was very small (0.03 µg L^{-1}) and insignificant (*Figure 3.2*). The water bodies in Denmark and Sweden are generally exposed to the same biogeographical condition, except that water bodies on the Jutland coast may experience more frequent upwelling of nutrient-rich bottom water due to the dominating winds from west (Kiørboe 1996). However, this phenomenon does not appear to affect the overall chlorophyll *a* level when compared to TN. Thus, in NEA 8b there is no need for adjusting chlorophyll *a* levels to account for biogeographical differences.

The inner coastal waters of NEA 8a showed a similar response in chlorophyll *a* to TN for Norway and Sweden (*Figure 3.2*). On average, Norwegian water bodies had 0.13 µg L^{-1} higher chlorophyll *a* concentrations when accounting for differences in TN, but this difference was small and not significant, and mainly driven by two high observations. Since this difference is small and there are no obvious biogeographical differences, there is no need to adjust the chlorophyll *a* metric.

In NEA 9, the Norwegian fjords were lower in both chlorophyll *a* and TN (2.79 µg L^{-1} and 17.9 µmol L^{-1}) than the Swedish fjords (3.59 µg L^{-1} and 22.8 µmol L^{-1}), and there was a chlorophyll *a* difference of 0.50 µg L^{-1} between the two countries when accounting for the TN concentrations (*Figure 3.2*). There was a considerable variation around the regression line and this chlorophyll *a* difference was not significant. It is possible that this difference, despite being relatively large, is caused by the high random variation in data and since there are no obvious biogeographical differences, the chlorophyll *a* metric is not adjusted.

In NEA 10 (open coastal waters), the difference in the common chlorophyll *a* metric between Norway and Sweden was small and not significant (0.18 µg L^{-1}) (*Figure 3.2*). These water bodies can be influenced to a varying degree by waters from the German Bight (Jutland Coastal Current, JCC), leading to increased levels of both TN and chlorophyll *a*. However, the influence of JCC is strongest in spring and will have only a minor influence when applying the common metric using data from May to September. Other important biogeographical differences are not known and due to the relatively small difference there is no need for adjusting the chlorophyll *a* metric.

In summary, the analysis revealed small differences in the common chlorophyll *a* metric between countries sharing the same type, but these differences are not believed to be caused by biogeographical differences. Consequently, there is no need to adjust for biogeographical differences in any of the five intercalibration types.

3.3 Intercalibrating reference conditions and class boundaries

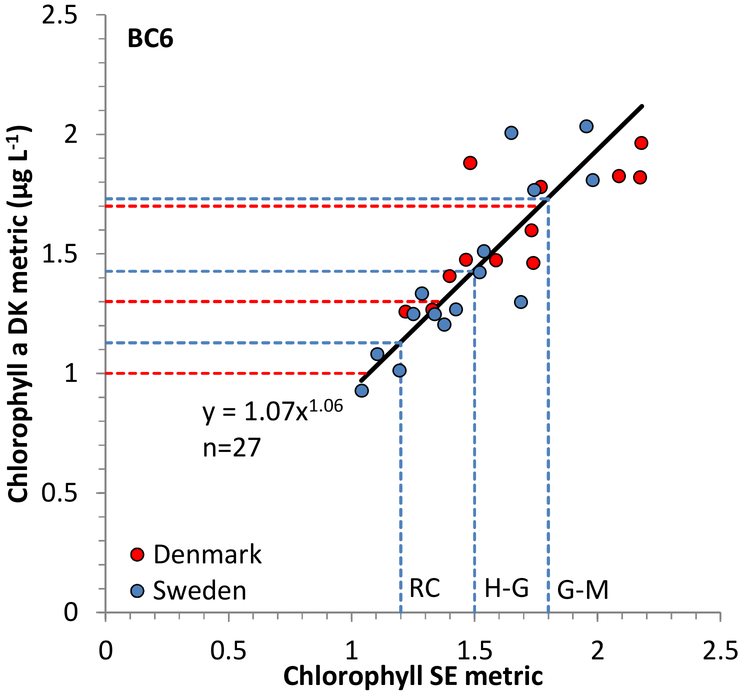
The strong relationships between the national and the common chlorophyll metric (*Figure 3.1*) were used to translate current national reference conditions (RC) and class boundaries for high-good (HG) and good-moderate (GM) to the common metric scale. After comparing these boundaries on the common scale, an intercalibrated value was decided (in most cases by averaging), after consulting with the national agencies, and translated back again to the original scale. For national types not included in the intercalibration, reference conditions and class boundaries were found by scaling the intercalibrated values within the shared type by the ratio of the existing values at the specific type divided by the existing value at the shared type.

First, the intercalibration results between Denmark and Sweden are shown starting from the Baltic Sea (BC6) and moving towards the Skagerrak (NEA 8b). Second, the intercalibration results between Norway and Sweden are shown (Skagerrak area) in the order moving from open coastal waters (NEA10) to inner coastal waters (NEA 8a) and fjords (NEA 9).

3.3.1 BC6 chlorophyll *a* intercalibration

In BC6, the Danish reference conditions and class boundaries (*Table 2.3*) were already on the common metric scale, so it was only necessary to translate the Swedish reference conditions and class boundaries (*Table 2.5*). The Swedish values were translated to 1.13 µg L^{-1} for RC, 1.43 µg L^{-1} for H-G and 1.73 µg L^{-1} for G-M (*Figure 3.3*). These translated values were indeed comparable to the corresponding Danish reference conditions and class boundaries.

Figure 3.3. Translating national reference conditions and class boundaries in BC6 to the common metric scale. There is no translation of the Danish chlorophyll *a* metric, since it is identical to the common metric.



It was agreed to employ the average of the Danish and Swedish reference conditions and class boundaries on the common metric scale as the intercalibrated values, which corresponded to 1.06 µg L^{-1} for RC, 1.36 µg L^{-1} for H-G and 1.72 µg L^{-1} for G-M. For the Swedish metric, these intercalibrated values on the common scale translated back to 1.14 µg L^{-1} for RC, 1.44 µg L^{-1} for H-G and 1.78 µg L^{-1} for G-M, which are slightly lower than the existing values (*Table 3.3*). For Denmark, the intercalibrated values were slightly higher than the existing values. These tendencies, slightly lowered values for Sweden and slightly elevated values for Denmark, were also seen in the values for the national types not included directly in the intercalibration. Consequently, EQR values in both countries were slightly modified.

Table 3.3. Existing and intercalibrated values for the national chlorophyll *a* metric in BC6. EQR values are calculated from the reference conditions and class boundaries. National types not included in the intercalibration are marked in red and their values have been scaled from the intercalibrated shared types.

National type	Existing reference conditions and boundaries					Intercalibrated reference conditions and boundaries				
	Chlorophyll *a* (µg L^{-1})			EQR		Chlorophyll *a* (µg L^{-1})			EQR	
	RC	H-G	G-M	H-G	G-M	RC	H-G	G-M	H-G	G-M
OW3b	1.0	1.3	1.7	0.8	0.6	1.06	1.36	1.72	0.78	0.62
OW3c	1.0	1.3	1.7	0.8	0.6	1.06	1.36	1.72	0.78	0.62
M2	1.3	1.6	2.1	0.8	0.6	1.38	1.68	2.12	0.82	0.65
SE-7	1.2	1.5	1.8	0.8	0.67	1.14	1.44	1.78	0.79	0.64
SE-8 (0-1)	15.7	20.2	25.2			14.9	19.3	25.0		
SE-8 (1-2)	12.4	15.9	19.9			11.7	15.2	19.7		
SE-8 (2-3)	9.5	12.2	15.2			8.99	11.7	15.1		
SE-8 (3-4)	6.9	8.9	11.1			6.53	8.52	11.0		
SE-8 (4-5)	4.8	6.1	7.6			4.54	5.84	7.54		
SE-8 (5-6)	3.0	3.9	4.8			2.84	3.73	4.76		
SE-8 (6-7)	1.7	2.1	2.7			1.61	2.01	2.68		
SE-8 (>7)	1.2	1.5	1.8	0.8	0.67	1.14	1.44	1.78	0.79	0.64
SE-9	1.2	1.5	1.8	0.8	0.67	1.14	1.44	1.78	0.79	0.64

3.3.2 NEA 8b chlorophyll *a* intercalibration – The Sound

In the Sound, which is a sub-division of NEA 8b where both Denmark and Sweden have specific reference and class boundaries, the Swedish values (*Table 2.5*) translated to 0.92 µg L^{-1} for RC, 1.13 µg L^{-1} for HG and 1.56 µg L^{-1} for GM on the common metric scale (*Figure 3.4*). These values were generally lower than the Danish values (*Table 2.3*).

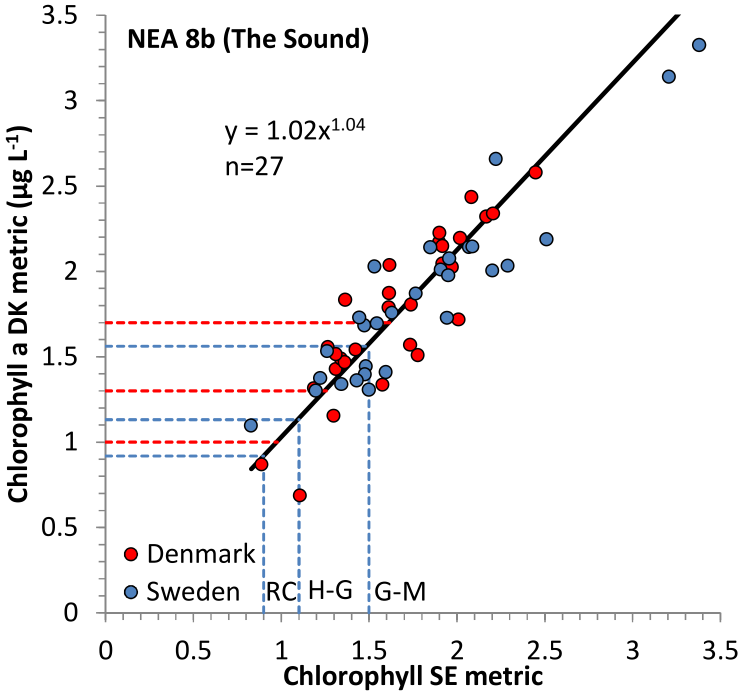


Figure 3.4. Translating national reference conditions and class boundaries in the Sound (part of NEA 8b) to the common metric scale. There is no translation of the Danish chlorophyll *a* metric, since it is identical to the common metric.

As for BC6, it was agreed to employ the average of the Danish and Swedish reference conditions and class boundaries on the common metric scale as the intercalibrated values, which corresponded to 0.96 µg L^{-1} for RC, 1.22 µg L^{-1} for H-G and 1.63 µg L^{-1} for G-M. For the Swedish metric these intercalibrated values on the common scale translated back to 0.94 µg L^{-1} for RC, 1.18 µg L^{-1} for H-G and 1.56 µg L^{-1} for G-M, which are slightly above the existing values (*Table 3.4*). For Denmark, the intercalibrated values were slightly lower than the existing values. EQR values in both countries were slightly modified.

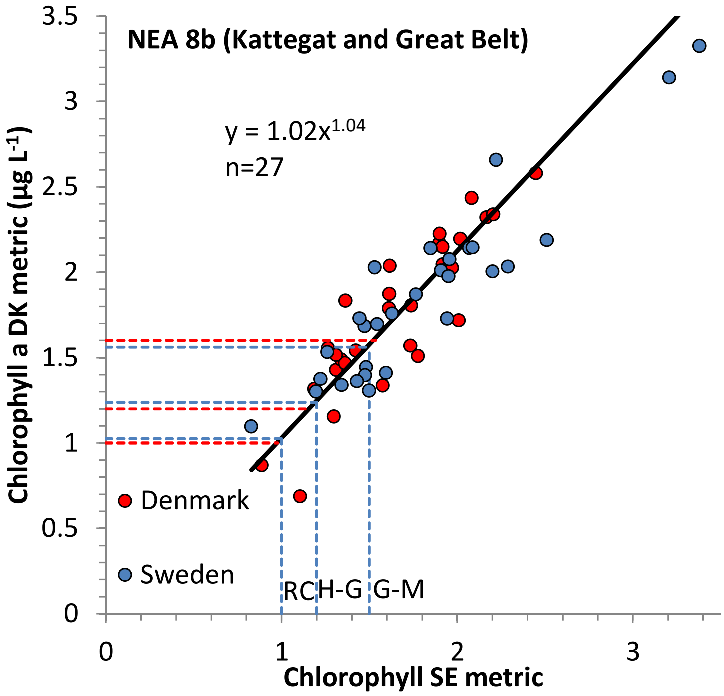
Table 3.4. Existing and intercalibrated values for the national chlorophyll *a* metric in the Sound (part of NEA 8b). EQR values are calculated from the reference conditions and class boundaries.

National type	Existing reference conditions and boundaries					Intercalibrated reference conditions and boundaries				
	Chlorophyll *a* (µg L^{-1})			EQR		Chlorophyll *a* (µg L^{-1})			EQR	
	RC	H-G	G-M	H-G	G-M	RC	H-G	G-M	H-G	G-M
N Øresund	1.0	1.3	1.7	0.8	0.6	0.96	1.22	1.63	0.79	0.59
SE-6	0.9	1.1	1.5	0.82	0.59	0.94	1.18	1.56	0.80	0.60

3.3.3 NEA 8b chlorophyll *a* intercalibration – The Kattegat and Great Belt

For the remaning part of NEA 8b (the Kattegat and Great Belt), similar reference conditions and class boundaries between Denmark and Sweden were obtained on the common metric scale (*Figure 3.5*). The Swedish values were translated to 1.02 µg L^{-1} for RC, 1.24 µg L^{-1} for H-G and 1.56 µg L^{-1} for G-M. These translated values were almost identical to the corresponding Danish reference conditions and class boundaries.

Figure 3.5. Translating national reference conditions and class boundaries in the Kattegat and Great Belt (part of NEA 8b) to the common metric scale. There is no translation of the Danish chlorophyll *a* metric, since it is identical to the common metric.



As for BC6 and NEA 8b (The Sound), it was agreed to employ the average of the Danish and Swedish reference conditions and class boundaries on the common metric scale as the intercalibrated values, which corresponded to 1.01 µg L^{-1} for RC, 1.22 µg L^{-1} for H-G and 1.58 µg L^{-1} for G-M. For the Swedish metric these intercalibrated values on the common scale translated back to 0.99 µg L^{-1} for RC, 1.18 µg L^{-1} for H-G and 1.52 µg L^{-1} for G-M (*Table 3.5*). For both Denmark and Sweden, the intercalibrated values were indeed similar to existing values, and these minor modifications were mirrored in the values for the national types not included directly in the intercalibration. Changes in the EQR values were also modest.

Table 3.5. Existing and intercalibrated values for the national chlorophyll *a* metric in the Kattegat and Great Belt (part of NEA 8b). EQR values are calculated from the reference conditions and class boundaries. National types not included in the intercalibration are marked in red and their values have been scaled from the intercalibrated shared types.

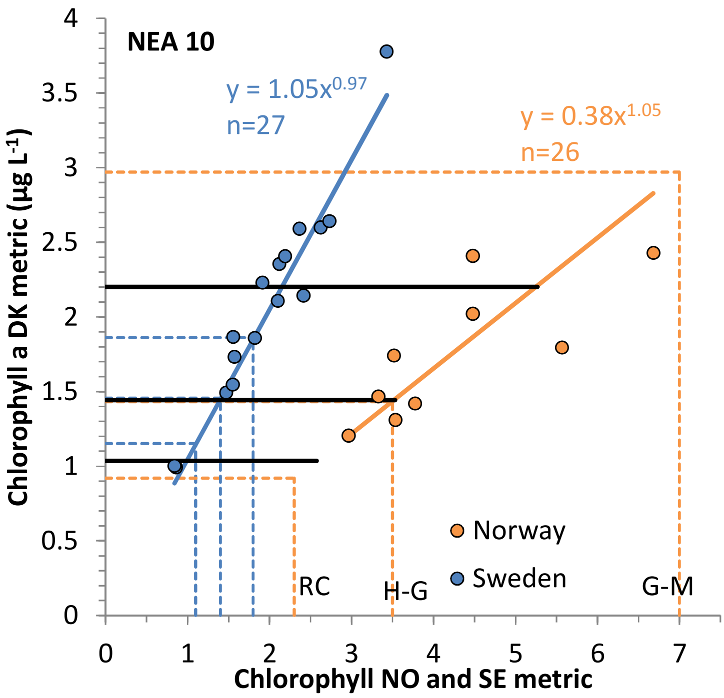
National type	Existing reference conditions and boundaries					Intercalibrated reference conditions and boundaries				
	Chlorophyll *a* (µg L^{-1})			EQR		Chlorophyll *a* (µg L^{-1})			EQR	
	RC	H-G	G-M	H-G	G-M	RC	H-G	G-M	H-G	G-M
OW1	1.0	1.2	1.6	0.8	0.6	1.01	1.22	1.58	0.83	0.64
(Ålbæk Bugt)	1.1	1.4	1.9	0.8	0.6	1.11	1.42	1.88	0.78	0.59
OW2	1.0	1.2	1.6	0.8	0.6	1.01	1.22	1.58	0.83	0.64
(Storebælt NV)	1.1	1.4	1.9	0.8	0.6	1.11	1.42	1.88	0.78	0.59
(Djursland Ø)	1.1	1.4	1.9	0.8	0.6	1.11	1.42	1.88	0.78	0.59
M1	1.3	1.6	2.1	0.8	0.6	1.32	1.63	2.08	0.81	0.63
- Inner Mariager Fjord	3.6	4.5	6.0	0.8	0.6	3.64	4.57	5.93	0.80	0.61
M2	1.3	1.6	2.1	0.8	0.6	1.32	1.63	2.08	0.81	0.63
- Inner Roskilde Fjord	2.2	2.7	3.6	0.8	0.6	2.23	2.74	3.56	0.81	0.63
M3	2.2	2.7	3.6	0.8	0.6	2.23	2.74	3.56	0.81	0.63
M4	2.2	2.7	3.6	0.8	0.6	2.23	2.74	3.56	0.81	0.63
O3	4.2	5.3	7.0	0.8	0.6	4.25	5.39	6.92	0.79	0.61
O4	4.2	5.3	7.0	0.8	0.6	4.25	5.39	6.92	0.79	0.61
P1	1.3	1.6	2.1	0.8	0.6	1.32	1.63	2.08	0.81	0.63
- Outer Mariager Fjord	2.2	2.7	3.6	0.8	0.6	2.23	2.74	3.56	0.81	0.63
P2	1.3	1.6	2.1	0.8	0.6	1.32	1.63	2.08	0.81	0.63
P3	2.2	2.7	3.6	0.8	0.6	2.23	2.74	3.56	0.81	0.63
- Kalundborg Fjord	1.3	1.6	2.1	0.8	0.6	1.32	1.63	2.08	0.81	0.63
- Århus Bugt	1.3	1.6	2.1	0.8	0.6	1.32	1.63	2.08	0.81	0.63
- Skive Fjord	3.6	4.5	6.0	0.8	0.6	3.64	4.57	5.93	0.80	0.61
P4	2.2	2.7	3.6	0.8	0.6	2.23	2.74	3.56	0.81	0.63
Slusefjorde[1]	4.8	6.0	8.0	0.8	0.6	4.86	6.10	7.91	0.80	0.61
- Hjarbæk Fjord	5.4	6.8	9.0	0.8	0.6	5.47	6.91	8.89	0.79	0.61
SE-1s	1.6	2.1	2.8	0.76	0.57	1.62	2.13	2.77	0.76	0.59
SE-4	1.0	1.2	1.5	0.83	0.67	0.99	1.18	1.52	0.84	0.65
SE-5	1.0	1.2	1.5	0.83	0.67	0.99	1.18	1.52	0.84	0.65
SE-25	1.8	2.1	2.7	0.86	0.67	1.82	2.13	2.67	0.85	0.68

[1]Nissum Fjord and Ringkøbing Fjord

3.3.4 NEA 10 chlorophyll *a* intercalibration

In NEA 10, both the Norwegian and Swedish reference conditions and class boundaries (*Table 2.4* and *Table 2.5*) were translated to the common metric scale (*Figure 3.6*). The Norwegian values were translated to 0.92 µg L^{-1} for RC, 1.43 µg L^{-1} for H-G and 2.97 µg L^{-1} for G-M, whereas the Swedish were translated to 1.15 µg L^{-1} for RC, 1.46 µg L^{-1} for H-G and 1.86 µg L^{-1} for G-M. For the reference condition, the difference between the two countries was small and for the high-good boundary the values of the two countries matched, but for the good-moderate boundary the translated boundaries differed by more than 1 µg L^{-1}.

Figure 3.6. Translating national reference conditions and class boundaries in NEA 10 to the common metric scale. The Danish metric has been chosen as the common chlorophyll *a* metric. The agreed intercalibrated values on the common metric scale are shown as black lines.



For the reference condition and high-good boundary it was agreed to employ the average of the Norwegian and Swedish values on the common metric scale, corresponding to 1.04 µg L^{-1} for RC and 1.44 µg L^{-1} for H-G. These values corresponded well with those for the open Skagerrak set by OSPAR. However, comparing the good-moderate boundaries with the target set by OSPAR for the open Skagerrak, it was assessed that the Norwegian G-M boundary was most likely too high. Hence, as opposed to an average of the two translated G-M boundaries, it was agreed to set the G-M boundary to 2.2 µg L^{-1}. These values translated back to 2.57 µg L^{-1} for RC, 3.53 µg L^{-1} for H-G and 5.26 µg L^{-1} for G-M for the Norwegian metric and 0.99 µg L^{-1} for RC, 1.39 µg L^{-1} for H-G and 2.14 µg L^{-1} for G-M for the Swedish metric (*Table 3.6*). These intercalibrated values imply that Norway should raise the RC value and lower the G-M boundary, whereas Sweden should lower the RC value and raise the G-M boundary. For the H-G boundary, the modifications were modest. Changes in EQR were considerable.

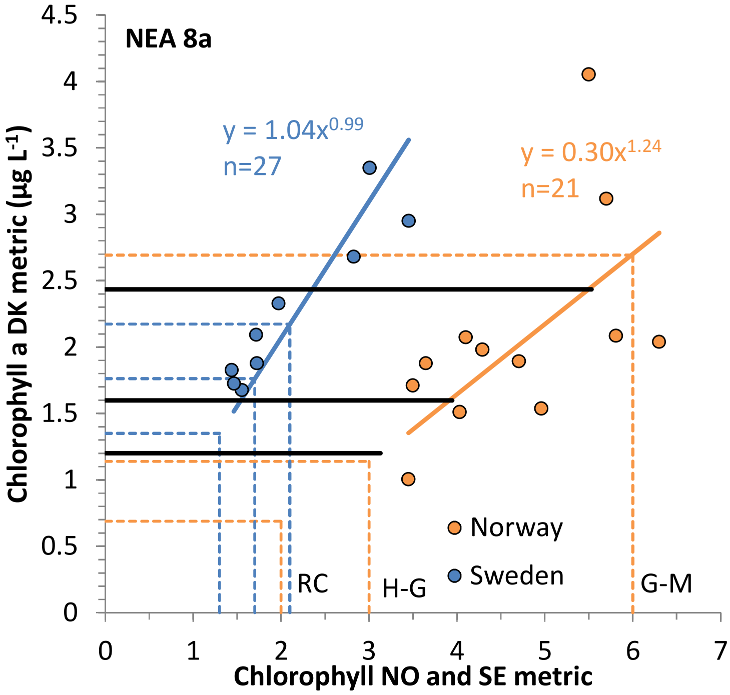
Table 3.6. Existing and intercalibrated values for the national chlorophyll *a* metric in NEA 10. EQR values are calculated from the reference conditions and class boundaries.

National type	Existing reference conditions and boundaries					Intercalibrated reference conditions and boundaries				
	Chlorophyll *a* (µg L^{-1})			EQR		Chlorophyll *a* (µg L^{-1})			EQR	
	RC	H-G	G-M	H-G	G-M	RC	H-G	G-M	HG	G-M
NO-1	2.3	3.5	7.0	0.66	0.33	2.57	3.53	5.26	0.73	0.49
SE-3	1.1	1.4	1.8	0.79	0.63	0.99	1.39	2.14	0.71	0.46

3.3.5 NEA 8a chlorophyll *a* intercalibration

As for NEA 10, both the Norwegian and Swedish reference conditions in NEA 8a were translated to the common metric scale (*Figure 3.7*). The Norwegian values were translated to 0.69 µg L^{-1} for RC, 1.14 µg L^{-1} for H-G and 2.69 µg L^{-1} for G-M, whereas the Swedish values were translated to 1.35 µg L^{-1} for RC, 1.76 µg L^{-1} for H-G and 2.17 µg L^{-1} for G-M. Differences between countries were generally large for all boundaries, all of them deviating by more than 0.5 µg L^{-1}.

Figure 3.7. Translating national reference conditions and class boundaries in NEA 8a to the common metric scale. The Danish metric has been chosen as the common chlorophyll *a* metric. The agreed intercalibrated values on the common metric scale are shown as black lines.



Comparing the translated reference conditions to OSPAR's from the open Skagerrak and the intercalibrated value in NEA 10, it was agreed to set the RC value to 1.20 µg L^{-1}. Since chlorophyll *a* levels are generally expected to increase towards land, which is also supported by the estimated chlorophyll *a* metrics (*Figure 3.1*), values in NEA 8a should be higher than in NEA 10. The H-G boundary was set to 1.60 µg L^{-1}, which is slightly above the average of the two countries' values and higher than the H-G boundary for NEA 10. For the G-M boundary, it was agreed to employ the average (2.43 µg L^{-1}) of the two countries' values on the common scale. The intercalibrated values on the common scale translated back to 3.13 µg L^{-1} for RC, 3.95 µg L^{-1} for H-G and 5.53 µg L^{-1} for G-M for the Norwegian metric and 1.15 µg L^{-1} for RC, 1.54 µg L^{-1} for H-G and 2.35 µg L^{-1} for G-M for the Swedish metric (*Table 3.7*). These intercalibrated values imply that Norway should raise the RC and H-G values and lower the G-M boundary, whereas Sweden should lower the RC and H-G values and raise the G-M boundary. EQR values based on the intercalibrated reference conditions and class boundaries were altered relative to the existing reference conditions and class boundaries.

Table 3.7. Existing and intercalibrated values for the national chlorophyll *a* metric in NEA 8a. EQR values are calculated from the reference conditions and class boundaries.

National type	Existing reference conditions and boundaries					Intercalibrated reference conditions and boundaries				
	Chlorophyll *a* (µg L-1)			EQR		Chlorophyll *a* (µg L-1)			EQR	
	RC	H-G	G-M	H-G	G-M	RC	H-G	G-M	H-G	G-M
NO-2	2.0	3.0	6.0	0.67	0.33	3.13	3.95	5.53	0.79	0.57
SE-1n	1.3	1.7	2.1	0.76	0.62	1.15	1.54	2.35	0.75	0.49

3.3.6 NEA 9 chlorophyll *a* intercalibration

For the fjords in NEA 9, the existing Norwegian and Swedish reference conditions in NEA 8a were translated to the common metric scale (*Figure 3.8*). The Norwegian values were translated to 1.00 µg L^{-1} for RC, 1.52 µg L^{-1} for H-G and 3.08 µg L^{-1} for G-M, whereas the Swedish were translated to 2.01 µg L^{-1} for RC, 2.48 µg L^{-1} for H-G and 3.55 µg L^{-1} for G-M. Differences between countries were large, ranging between 0.5 and 1.0 µg L^{-1} for the three values to be intercalibrated.

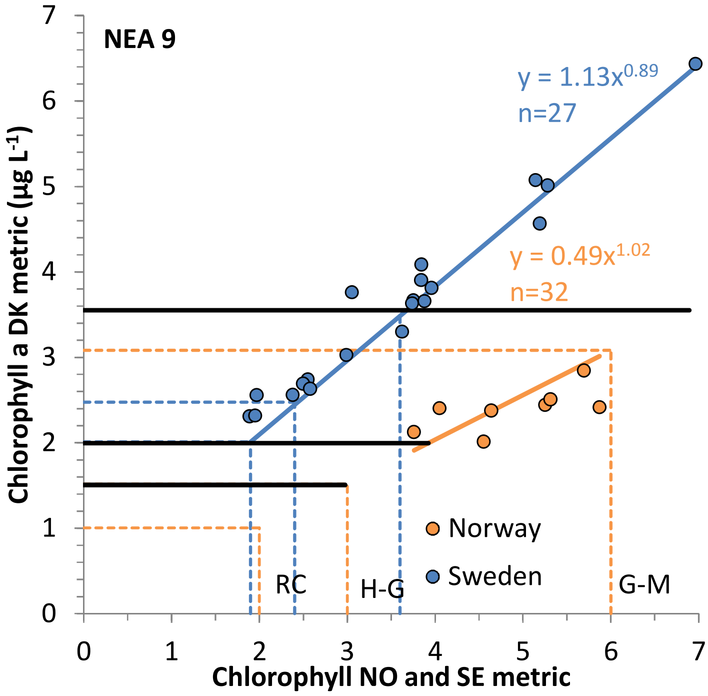


Figure 3.8. Translating national reference conditions and class boundaries in NEA 9 to the common metric scale. The Danish metric has been chosen as the common chlorophyll *a* metric. The agreed intercalibrated values on the common metric scale are shown as black lines.

Comparing the translated RC and H-G values with the intercalibrated values in NEA 8a and NEA 10, acknowledging an expected increase in chlorophyll *a* in the fjords relative to inner and open coastal waters for water bodies with good or worse status (chlorophyll *a* levels might be lower in fjords with an unaffected status), it was found that the Norwegian RC and H-G values were probably too low and the Swedish RC and H-G values were probably too high. It was agreed to employ averages of the two countries' values as intercalibrated values, corresponding to 1.51 µg L^{-1} for RC and 2.00 µg L^{-1} for H-G on the common metric scale. For the G-M boundary, the Swedish G-M value (3.55 µg L^{-1}) was adopted as the intercalibrated G-M boundary on the common metric scale. These intercalibrated values on the common scale translated back to 2.98 µg L^{-1} for RC, 3.92 µg L^{-1} for H-G and 6.90 µg L^{-1} for G-M for the Norwegian metric and 1.37 µg L^{-1} for RC, 1.89 µg L^{-1} for H-G and 3.60 µg L^{-1} for G-M for the Swedish metric (*Table 3.8*). These intercalibrated values imply that Norway should raise all their values and that Sweden should lower reference condition and high-good boundary. These changes in reference conditions and class boundaries also affected the calculated EQR values.

Table 3.8. Existing and intercalibrated values for the national chlorophyll *a* metric in NEA 9. EQR values are calculated from the reference conditions and class boundaries.

National type	Existing reference conditions and boundaries					Intercalibrated reference conditions and boundaries				
	Chlorophyll *a* (µg L^{-1})			EQR		Chlorophyll *a* (µg L^{-1})			EQR	
	RC	H-G	G-M	H-G	G-M	RC	H-G	G-M	HG	G-M
NO-3	2.0	3.0	6.0	0.67	0.33	2.98	3.92	6.90	0.76	0.43
SE-2	1.9	2.4	3.6	0.79	0.53	1.37	1.89	3.60	0.73	0.38

4 Conclusions

Denmark, Norway and Sweden share the common intercalibration types BC6, NEA 8a, NEA 8b, NEA 9 and NEA 10; the first area located within the Baltic Geographical Intercalibration Group and the four latter located in the North East Atlantic Geographical Intercalibration Group. The three countries have the same data acquisition for assessing phytoplankton biomass (using chlorophyll *a*), but assessment methods differ. The aim of this report is to intercalibrate reference conditions and class boundaries for the three different metrics following the EC guidelines.

A large dataset with monitoring data from all three countries has been combined and partitioned into four 6-year assessment periods. The three national chlorophyll *a* metrics have been calculated for all water bodies and assessment periods. For comparing chlorophyll *a* levels in these water bodies and assessment periods, the Danish metric was selected as the common metric. Both the Norwegian and Swedish metric correlated strongly with the Danish metric. Differences between countries within the five types were generally small and could not be attributed to any known biogeographical difference that was not related to the nutrient pressure. Therefore, no adjustments were made as part of the benchmark process.

Using the established relationships between national chlorophyll *a* metrics, existing reference conditions and class boundaries for the three countries were translated to the common metric scale for each of the five types. Differences in these values between Denmark and Sweden in BC6 and NEA 8b were generally small, whereas differences between Norway and Sweden were larger. In most cases, intercalibration between countries was done by averaging boundaries, but in NEA 8a, 9 and 10 some of the values were set to appropriate values, obeying the natural gradient from land towards the open sea and reference conditions and targets for good environmental status set by OSPAR for the open Skagerrak. The intercalibrated values in this report have been presented to relevant experts at the Danish Nature Agency (Naturstyrelsen), Norwegian Environment Agency (Miljødirektoratet) and Swedish Agency for Marine and Water Management (Havs- och Vattenmyndigheten). All the three agencies have accepted to revise their chlorophyll *a* reference conditions, high-good and good-moderate boundaries for the intercalibrated water bodies (*Table 4.1*) to those stated in this report.

Table 4.1. Summary of existing and intercalibrated values for the national chlorophyll *a* metric in the national types for Denmark, Norway and Sweden, shared between countries.

National type	Existing reference conditions and boundaries					Intercalibrated reference conditions and boundaries				
	Chlorophyll *a* (µg L^{-1})			EQR		Chlorophyll *a* (µg L^{-1})			EQR	
	RC	H-G	G-M	H-G	G-M	RC	H-G	G-M	H-G	G-M
DK-OW1	1.0	1.2	1.6	0.8	0.6	1.01	1.22	1.58	0.83	0.64
DK-OW2	1.0	1.2	1.6	0.8	0.6	1.01	1.22	1.58	0.83	0.64
DK-OW2 (Nordlige Øresund)	1.0	1.3	1.7	0.8	0.6	0.96	1.22	1.63	0.79	0.59
DK-OW3b	1.0	1.3	1.7	0.8	0.6	1.06	1.36	1.72	0.78	0.62
DK-OW3c	1.0	1.3	1.7	0.8	0.6	1.06	1.36	1.72	0.78	0.62
NO-1	2.3	3.5	7.0	0.66	0.33	2.57	3.53	5.26	0.73	0.49
NO-2	2.0	3.0	6.0	0.67	0.33	3.13	3.95	5.53	0.79	0.57
NO-3	2.0	3.0	6.0	0.67	0.33	2.98	3.92	6.90	0.76	0.43
SE-1n	1.3	1.7	2.1	0.76	0.62	1.15	1.54	2.35	0.75	0.49
SE-2	1.9	2.4	3.6	0.79	0.53	1.37	1.89	3.60	0.73	0.38
SE-3	1.1	1.4	1.8	0.79	0.63	0.99	1.39	2.14	0.71	0.46
SE-4	1.0	1.2	1.5	0.83	0.67	0.99	1.18	1.52	0.84	0.65
SE-5	1.0	1.2	1.5	0.83	0.67	0.99	1.18	1.52	0.84	0.65
SE-6	0.9	1.1	1.5	0.82	0.59	0.94	1.18	1.56	0.80	0.60
SE-7	1.2	1.5	1.8	0.8	0.67	1.14	1.44	1.78	0.79	0.64
SE-9	1.2	1.5	1.8	0.8	0.67	1.14	1.44	1.78	0.79	0.64

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INTERCALIBRATION OF CHLOROPHYLL *A* BETWEEN DENMARK, NORWAY AND SWEDEN

Western Baltic (BC6), Kattegat (NEA8b) and Skagerrak (NEA8a, NEA9 and NEA10)

This report documents the intercalibration of chlorophyll *a* between Denmark, Norway and Sweden in the shared types within the Baltic and Northeast Atlantic geographical intercalibration groups. A large dataset, combining monitoring data from the three countries, has been used to establish relationships between national metrics for chlorophyll *a*. Potential adjustment for biogeographical differences was deemed unnecessary. Based on these relationships, present national reference conditions and class boundaries for chlorophyll *a* were compared on a common scale. In most cases, differences were small and intercalibrated values were obtained by averaging translated national reference conditions and boundaries. In a few cases, intercalibrated values were modified to better reflect the land-sea gradient and to be consistent with OSPAR's values for the open Skagerrak. The intercalibrated values will be submitted by the national agencies in Denmark, Norway and Sweden to the European Commission decision on intercalibration.

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