# Rådgivning om bestandsvurdering og TAC for hjertemuslingefiskeri 2023-2024

## RÅDGIVNINGSNOTAT FRA DTU AQUA

| | |
|---|---|
| **Til:** | Fødevareministeriet, Kontoret for Bæredygtigt fiskeri |
| **Forfatter(e):** | Pedro Seabra de Freitas, Camille Saurel, Jeppe Olsen og Jens Kjerulf Petersen |
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| **Dato:** | 4. september 2023 |
| **J.nr.:** | 23-1009397 |
| **Indsatsområde på ydelsesaftalen:** | Erhvervsfiskeri |

## Anmodning

DTU Aqua anmodes om at udarbejde et forslag til en bæredygtig kvote af hjertemuslinger i Limfjorden for sæsonen 2023-2024.

Forslaget til kvoten kan, som i tidligere udarbejdede notater, baseres på en samlet faglig vurdering, hvor de seneste gennemsnitlige landinger pr. sæson bidrager til estimering af kvoten.

## Resumé

Dette notat præsenterer DTU Aquas vurderinger og anbefalinger i forhold til at fastlægge kvoter for hjertemuslingefiskeriet i Limfjorden. Rådgivningen er givet som en samlet faglig vurdering baseret på de nyeste landingsdata for hjertemuslinger pr. sæson, "blackbox" data og undersøgelser af bestanden fra juni 2023 i muslingeområder Kås Bredning (MO 9), Salling Sund (syd og nord, MO 11 og 13) og Sønder Bredning (MO 15).

Der blev landet 8.001 tons hjertemuslinger i Limfjorden i sæsonen 2022-2023, hvilket var de næsthøjeste landinger siden 2014-2015 og fulgte rekordhøje landinger den foregående sæson. Landingerne var 1.801 tons eller 29 % over de foreslåede TAC for sæsonen 2022-2023 (Notat jnr. 22-1008192). Landingerne i 2022-2023 var et resultat af bl.a. rekordhøje landinger fra Salling Sund syd (MO 11), et lille område der sjældent bidrager til høje landinger, mens landingerne fra de to kerneområder for hjertemuslingefiskeri Kås Bredning og Sønder Bredning var på historisk lave niveauer. Bortset fra Salling Sund Syd kom landingerne primært fra tidligere fiskede banker af hjertemuslinger, men med væsentligt lavere fangstrater.

I juni 2023 blev hjertemuslingbestanden i fire hovedfiskeområder (MO 9, 11, 13 og 15) af DTU Aqua anslået til kun 6.559 tons. Der blev ikke observeret små muslinger eller yngel, og dermed er al biomasse tilgængelig for fiskeriet. Til sammenligning har de fire undersøgte områder produceret middellandinger på 6.572 tons/sæson siden 2017-2018, mens Kås Bredning alene i foråret 2021 havde en hjertemuslingbiomasse på 27.061 tons. Der er således betydeligt lavere biomasse end tidligere år og ingen nyere rekruttering i de vigtigste fiskeriområder, der siden 2017-2018 har bidraget med 86% af landingerne. Dermed kan biomassen af hjertemuslinger i de undersøgte områder være under niveauer, der sikrer fremtidig rekruttering og dermed potentielt under niveauer, der kan sikre et fremtidigt levedygtigt fiskeri og bevarer de økosystem tjenester, som bestande af hjertemuslinger leverer.

DTU Aqua anbefaler en meget konservativ tilgang til hjertemuslingfiskeri i Limfjorden i 2023-2024. DTU Aqua anbefaler en særskilt TAC i 2023-2024 for de fire undersøgte områder (MO 9, 11, 13 og 15) på maksimalt 2.165 tons for at begrænse yderligere re-

duktion i bestanden i, hvad der vurderes at være væsentligt udtømte områder. En TAC på 2.165 tons svarer til den fælles høstprocent på 33%. Det anbefales at overveje en endnu mere konservativ tilgang med en høstprocent på 20 % svarende til en TAC på 1.312 tons. DTU Aqua kan ikke foreslå en TAC i 2023-2024 for områder, hvor forekomsten og strukturen af hjertemuslingebestande i disse områder ikke er kendt. Disse områder kan potentielt blive vigtige for de samlede landinger i 2023-2024.

## Contents

## 1. Introduction

This note presents DTU Aqua recommendations toward establishing sustainable catch limits for cockle fishing in the Limfjorden in the coming 2023-2024 season, considering a future scenario where cockles are a separate fishery managed independently from the blue mussel fishery.

DTU Aqua recommendations for catch limits (Total Allowable Catch, TAC) in the Limfjorden cockle fishery for the coming 2023-2024 season are based on expert evaluation of two sources of information:

- Fishery dependent information
    a. Spatial and temporal patterns of cockle landing statistics in recent fishing seasons.
    b. Fishing patterns obtained from black box and Elogs (BB - BlackBox R2, Anchor Lab, Copenhagen; Fiskeristyrelsen) data of the blue mussel/cockle fishery and associated landings.
- Fishery independent information
    c. Spring 2023 survey of cockle abundance and population structure of four main fishing areas (muslingeområder, MO) Kås Bredning (MO 9), Salling Sund Syd (MO 11) and Nord (MO 13) and Sønder Bredning (MO 15).
    d. Surveys in 2021 and 2022, even if not comprehensive, provided data on cockle populations in the main fishing area Kås Bredning.

## 2. Cockle Limfjorden fishery: Status after 2022-2023 season

### Seasonal landings

Below are described the seasonal landings (September to June) in the Limfjorden cockle fishery.

8,001 tonnes live weight of cockles were landed in the Limfjorden in the last fishing season of 2022-2023 (October to April).

The 2022-2023 season was the second consecutive season with landings higher than the recommended TAC:

- 1,801 tonnes or 29% above the proposed TAC of 6,200 tonnes (Notat jnr. 22-1008192).
- In comparison, in the 2021-2022 season landings were 4,274 tons or 68.4% above the proposed TAC of 6,250 tons (Notat jnr. 21-1033607).

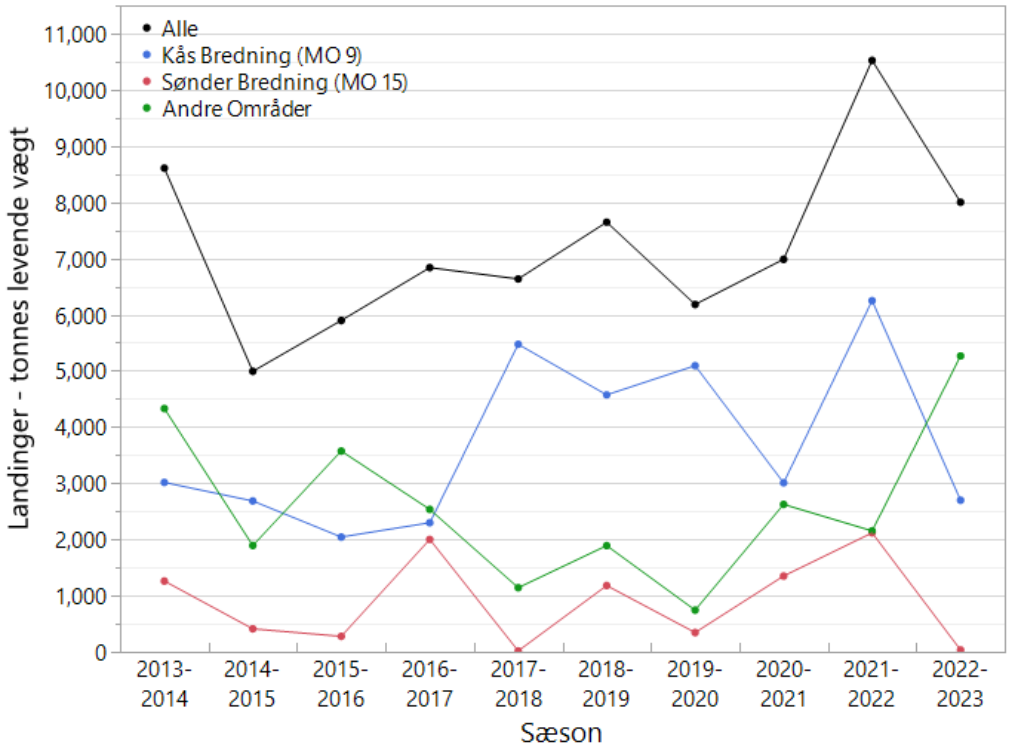


**Figure 1. Cockle landings (tonnes live weight) per fishing season for the Limfjorden: total landings from all areas (black, alle); Kås Bredning fishing area (MO 9; blue); Sønder Bredning (MO 15; red); and from other areas (green). Data from Fiskeristyrelsen.**

In summary, in the 2022-2023 season landings were (Figure 1 and Table 1):

- Third highest on record since 2013 and followed the record highest landings of 2021-2022 (Notat jnr. 22-1008192)
- 1,143 tonnes or 16.7% above mean landings of 6,858 tonnes (±239 tonnes, SE) in 5 reference seasons (2016 to 2021, excludes 2021-2022 with record landings).
- 104 tonnes or 1.3% above mean landings of 7,897 tonnes (±1,334 tonnes, SE) in the previous 3 seasons (2019-2022).

### Landings: Fishing areas (muslingeområder, MO)

The contribution of separate fishing areas (MO) to cockle landings in 2022-2023 was different from recent seasons (Figure 1, Tables 1 and 2).

**Table 1. Limfjorden cockle landings (tonnes of live weight) per fishing area (muslingeområder, MO) and season (September-June) since 2013. Data from Fiskeristyrelsen**

| | Fishing Season | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fishing Area** | 2022-2023 | 2021-2022 | 2020-2021 | 2019-2020 | 2018-2019 | 2017-2018 | 2016-2017 | 2015-2016 | 2014-2015 | 2013-2014 | All |
| Kås Bredning (9) | 2,699 | 6,250 | 3,009 | 5,093 | 4,574 | 5,474 | 2,298 | 2,044 | 2,687 | 3,016 | 34,446 |
| Sønder (15) | 36 | 2,120 | 1,350 | 345 | 1,182 | 19 | 2,003 | 278 | 412 | 1,261 | 8,968 |
| Salling Syd (11) | 5,068 | 11 | 0 | 0 | 739 | 0 | 0 | 0 | 0 | 3,181 | 3,930 |
| Visby (25) | 15 | 9 | 0 | 621 | 9 | 72 | 2,466 | 1,342 | 0 | 0 | 4,519 |
| Livø Vest (35) | 7 | 15 | 6 | 13 | 19 | 27 | 34 | 1,334 | 1,465 | 947 | 3,860 |
| Venø Bugt (7) | 0 | 642 | 1,636 | 0 | 1,096 | 4 | 0 | 0 | 0 | 0 | 3,379 |
| Venø Bugt (8) | 0 | 0 | 946 | 97 | 28 | 1,016 | 0 | 8 | 0 | 0 | 2,094 |
| Salling Nord (13) | 172 | 1,289 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,289 |
| Dragstrup (26) | 0 | 0 | 0 | 0 | 0 | 3 | 11 | 869 | 0 | 0 | 883 |
| Venø Sund (5) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 256 | 0 | 263 |
| Venø Sund (6) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 150 | 97 | 247 |
| Thisted Øst (30) | 0 | 180 | 0 | 0 | 0 | 0 | 18 | 0 | 8 | 0 | 206 |
| Andre Områder | 4 | 9 | 37 | 14 | 0 | 21 | 8 | 15 | 15 | 106 | 225 |
| **Total** | 8,001 | 10,524 | 6,985 | 6,182 | 7,647 | 6,636 | 6,838 | 5,897 | 4,993 | 8,608 | 64,310 |

**Table 2. Relative landings in percentage of total landings from the Limfjorden per fishing area (muslingeområder, MO) for the last two seasons 2022-2023 and 2021-2022 seasons, the five reference seasons (2017-2018 to 2021-2022), the first four seasons (2013-2014 to 2016-2017) and all seasons (2013 to 2022).**

| Fishing Area | 2022-2023 | 2021-2022 | 2017-2022 | 2013-2017 | All |
|---|---|---|---|---|---|
| | % | % | % | % | % |
| Kås Bredning (9) | 33.7 | 59.4 | 64.3 | 38.1 | 51.4 |
| Sønder Bredning (15) | 0.5 | 20.1 | 13.2 | 15.0 | 12.5 |
| Salling Sund Syd (11) | 63.3 | 0.1 | 2.0 | 12.1 | 12.4 |
| Visby Bredning (25) | 0.2 | 0.1 | 1.9 | 14.5 | 6.3 |
| Livø Bredning Vest (35) | 0.1 | 0.1 | 0.2 | 14.4 | 5.3 |
| Venø Bugt Nord (7) | 0 | 6.1 | 8.9 | 0 | 4.7 |
| Venø Bugt Syd (8) | 0 | 0 | 5.5 | 0 | 2.9 |
| Salling Sund Nord (13) | 2.1 | 12.3 | 3.4 | 0 | 2.0 |
| Other areas | 0.1 | 1.8 | 0.7 | 5.9 | 2.5 |

Historically, Kås Bredning (MO 9) is the main producing area and the only area with significant landings every season (Table 1). In 2022-2023 it was not the main source of landings and produced only 2,699 tonnes or 33.7% of total landings. Low cockle landings from Kås Bredning in 2022-2023 are not unique but were the lowest since 2017-2018 and only 55% of mean landings in that period (Table 1). Low landings from Kås Bredning in 2022-2023 support observations of no successful spatfall in 2020 and 2021 reported in previous notats (Notat jr. 21-1033607; Notat jnr. 22-1008192) and support a lack of recent recruitment into the harvestable stock.

Historically, Sønder Bredning (MO 15) is the second most important area, although it does not produce significant landings every season (Table 1). In 2022-2023, Sønder Bredning had insignificant landings of only 36 tonnes, a significant reduction from the two previous seasons (Figure 1, Tables 1 and 2). Landings from Sønder Bredning in 2022-2023 were the lowest since 2017-2018 and only 3.6% of mean landings in that period (Table 1).

Landings from secondary areas (i.e. other than MO 9 and 15) were 5,266 tonnes or 65.8% of all landings in 2022-2023, the highest since 2013 (Figure 1, Tables 1 and 2). Landings from secondary areas were 308% of mean landings since 2017-2018, and higher than landings from Kås Bredning for the first time in that period. No landings

were obtained from Venø Bugt (MO 7 and 8), that has been a significant source of cockle landings in the previous two seasons (Tables 1 and 2).

Almost all landings from secondary areas originated from one area, Salling Sund Syd (MO 11), at 5,068 tonnes or 63.3% of all 2022-2023 landings. Landings from Salling Sund Syd were the highest it ever produced, and only the third season with significant landings, the others being 2013-2014 with 3,181 tonnes and 2018-2019 with 739 tonnes (Table 1). Only the main fishing area Kås Bredning produced higher landings in a single season than Salling Sund Syd in 2022-2023, and only in three seasons since 2013 (Table 1).

**Fishing patterns**

Cockle fishing in the Limfjorden in the 2022-2023 season occurred almost exclusively in three fishing areas, in Kås Bredning and Salling Sund Syd and to less degree in Salling Sund Nord (Tables 1 and 2, Figure 2). Total fished area in 2022-2023 was similar to the previous season (Table 3). See Appendix 1 for definition of what constitutes a cockle bed and how it was identified.

In Kås Bredning, a similar number of cockle beds were fished as in the previous seasons, while fished area increased by ca. 15%, but with 62.5% lower landings per fished bed area (tonnes/km$^2$; Table 3 and Figure 2). In Salling Sund Nord, landings per fished area were also lower by 73.3% than in the previous season, but from half the cockle beds and fished area (Table 3 and Figure 2). In Salling Sund Syd, two cockle beds were fished with ca. half the area of Kås Bredning fished beds, covering 26.5% of the total available fishable area (i.e. deeper than 3 m). Landings per fished area were ca. three times higher than in Kås Bredning and at levels similar to high producing areas in the two previous seasons, between 1,120 and 2,275 tonnes/km$^2$ (Table 3 and Figure 2; Notat jnr. 22-1008192).

Several cockle beds were fished both in 2022-2023 and the previous season, with significant overlap between seasons (Table 3 and Figure 2). In 2022-2023 the fishery relied to a large extent on the same beds fished in the previous season in Kås Bredning and Salling Sund Nord: four beds overlapped by 62% in Kås Bredning and one bed overlapped by 72% in Salling Sund Nord (Table 3). Excluding Salling Sund Syd that had not been fished since 2018-2019 (Table 1).

By 2022-2023, cockle beds in Kås Bredning and Salling Sund Nord were fished for the third and second consecutive seasons and catch rates were significantly lower than in previous seasons (Table 3; Notat jnr. 22-1008192).

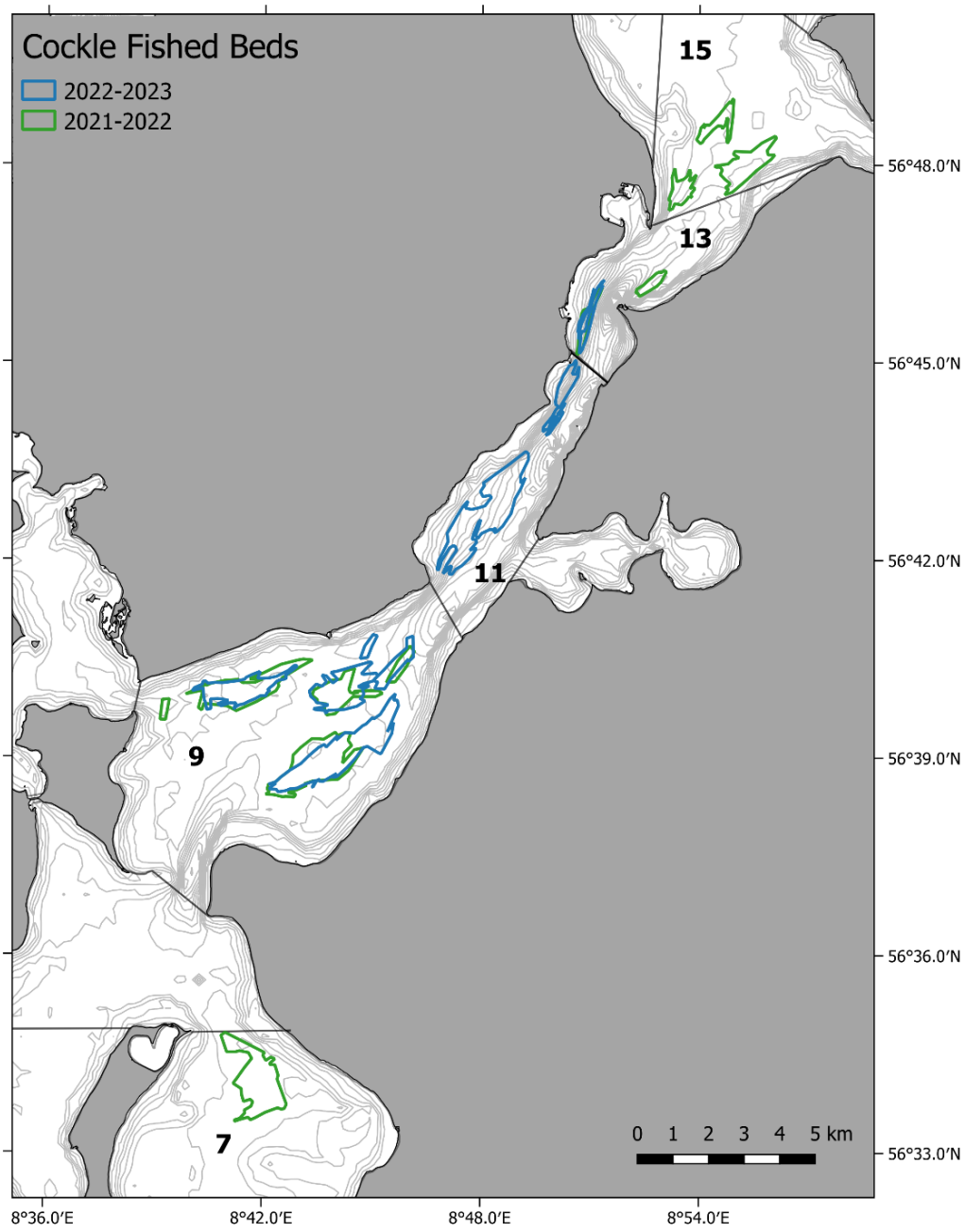


**Figure 2. Location of fished cockle beds in Venø Bugt (MO 7), Salling Sund Syd and Nord (MO 11 and 13), Kås Bredning (MO 9) and Sønder Bredning (MO 15) in the 2022-2023 season (blue) and the previous 2021-2022 season (green). Locations determined from black-box data and fishing information provided by Foreningen Muslingeerhvervet.**

**Table 3. Fished cockle beds in fishing areas (muslingeområder, MO) in the 2022-2023 season and the previous 2021-2022 season: number and area of fished beds (km$^2$); % of beds fished; tracks per bed area (km$^2$); fishing effort as number of times 50m cells were dredged (Appendix 1); landings per dredged area (tonnes/km$^2$); % of fishable area (> 3 m depth) dredged; and overlap between fished beds in 2022-2023 and the previous season.**

| Season | 2022-2023 | | | | | | | 2021-2022 | | | | Overlap | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fishing Area | Number beds | Area of beds (km$^2$) | % Bed fished | Tracks/ km$^2$ | Times dredged | Landings tonnes/ km$^2$ | % Area dredged | Number beds | Area of beds (km$^2$) | Landings tonnes/ km$^2$ | % Area dredged | Number beds | Area of beds (km$^2$) | % |
| Kås Bredning (9) | 5 | 6.1 | 83.6 | 919 | 3.4 | 439 | 12.0 | 5 | 5.3 | 1,170 | 11.1 | 4 | 3.8 | 61.7 |
| Sønder Bredning (15) | 0 | | | | | | | 3 | 1.9 | 1,120 | 5.5 | | | |
| Salling Sund Syd (11) | 2 | 3.3 | 88.2 | 2,035 | 5.7 | 1,538 | 24.1 | 0 | | | | 0 | 0 | 0 |
| Salling Sund Nord (13) | 1 | 0.3 | 56.7 | 1,015 | 2.6 | 608 | 2.0 | 2 | 0.6 | 2,275 | 5.0 | 1 | 0.2 | 72.3 |
| Venø Bugt Nord (7) | 0 | | | | | | | 1 | 2.0 | 322 | 4.3 | | | |
| Venø Bugt Syd (8) | 0 | | | | | | | 0 | | | | | | |
| Total | 8 | 9.7 | 78.6 | 1,303 | 4.2 | 819 | 12.7 | 10 | 9.8 | 1,043 | 5.1 | 5 | 4.0 | 41.0 |

Recruitment and growth in Kås Bredning and Salling Sund Nord, did not compensate for natural and fishing mortality over the last two to three seasons. In 2022-2023 the fishery thus relied on an ageing and decreasing population for landings from these two areas.

The fishery fished intensively the cockle beds, with 78.6% of the beds area dredged at least once (Table 3, Figure A1 in Appendix 1). Most of the cockle catches (84%) came from a small fraction of the cockle beds (33%; Figure A2 in Appendix 1).

## 3. Cockle populations in the Limfjorden: Spring 2023 status

### Spring 2023 survey

In June 2023, DTU Aqua conducted an intensive survey of cockle populations in the Limfjorden (Figure A3 in Appendix 2) as part of the COCKLE II project (EMFF/Fiskeristyrelsen, jr. 33113-B-20-172). The 2023 survey responded to the request from Kontor for Bæredygtig Fiskeri (Ministeriet for Fødevarer, Landbrug og Fiskeri) for advice on a sustainable quota/catch limit for cockle fishing in the Limfjorden for the coming 2023-2024 season.

The survey concentrated on the historically the two most important fishing areas (muslingeområder, MO) and on two fishing areas important in the last two seasons (Table 1 and Figure A3): Kås Bredning, Sønder Bredning, Salling Sund Syd and Salling Sund Nord. Venø Bugt and Visby Bredning that often produced significant landings in recent seasons, although irregularly, could not be surveyed. Surveyed areas were responsible for 86% of cockle landings in the Limfjorden since 2017-2018 (Table 1). The survey sampled 1077 stations on a 250 m grid covering historical fished cockle grounds (Figure A3 in Appendix 2). Since the abundance of the lagoon cockle, *Cerastoderma glaucum*, was extremely low at 0.2%, all values in this notat refer to the common cockle, *Cerastoderma edule*.

### Cockle abundance and distribution

In spring 2023, cockles generally occurred in previously fished cockle beds, with few exceptions in the northeastern part of Kås Bredning and Sønder Bredning (Figure 3).

Cockle abundance in spring 2023 was low in all four fishing areas surveyed (Table 4). In the spring 2021 survey of Kås Bredning 33% of stations had cockles (247 out of 738; Notat jnr. 21-1033607), while in spring 2023 a smaller proportion of stations had cockles: 13% in Kås Bredning, 25% in Salling Sund Syd, 1.6% in Salling Sund Nord and 5.2% in Sønder Bredning (Table 4, Figures 3 and 4).

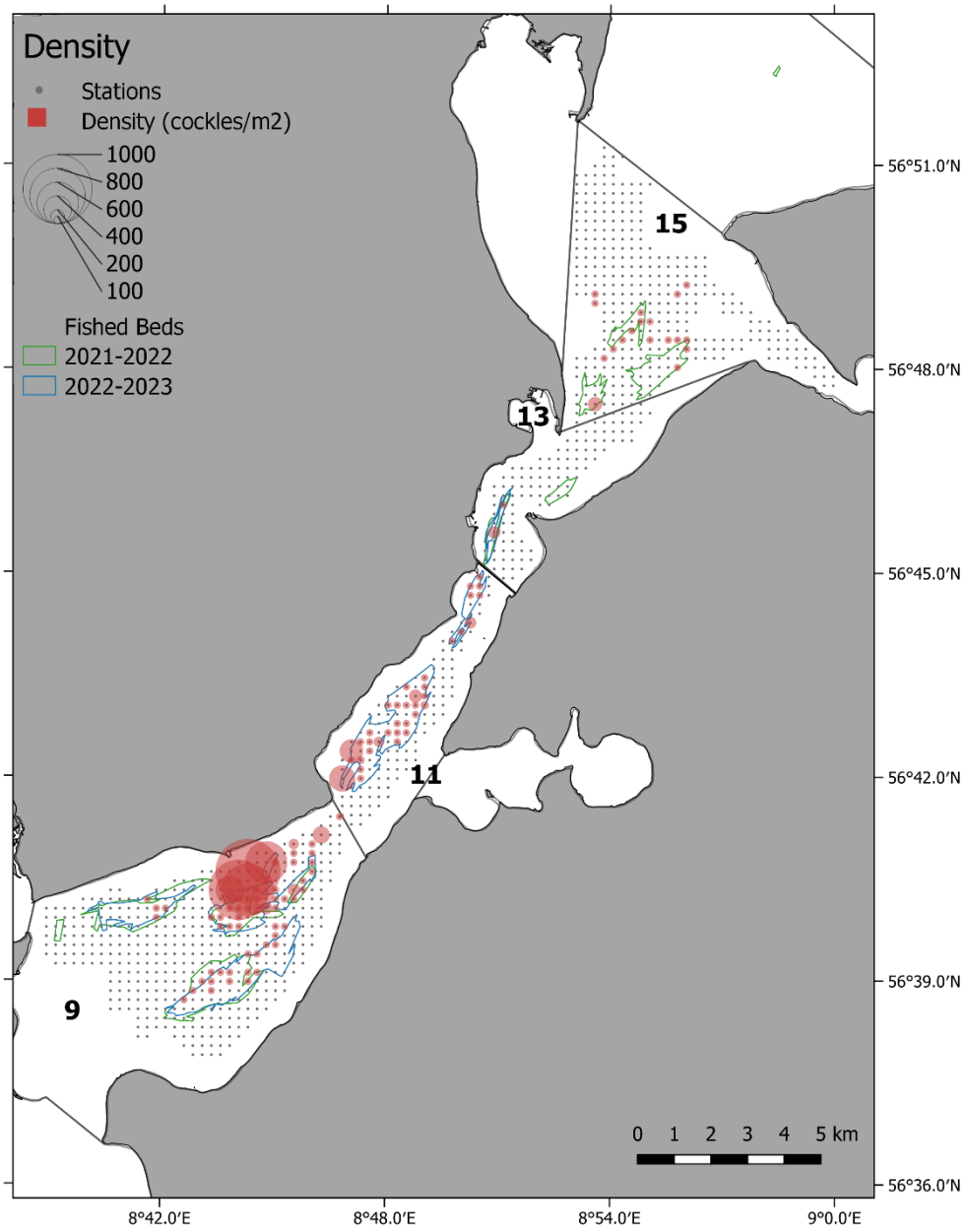


**Figure 3. Cockle density (cockles/m$^2$) in Kås Bredning (MO 9), Salling Sund Syd (MO 11), Salling Sund Nord (MO 13) and Sønder Bredning (MO 15) in spring 2023. Superimposed are fished cockle beds in 2021-2022 (green) and 2022-2023 (blue).**

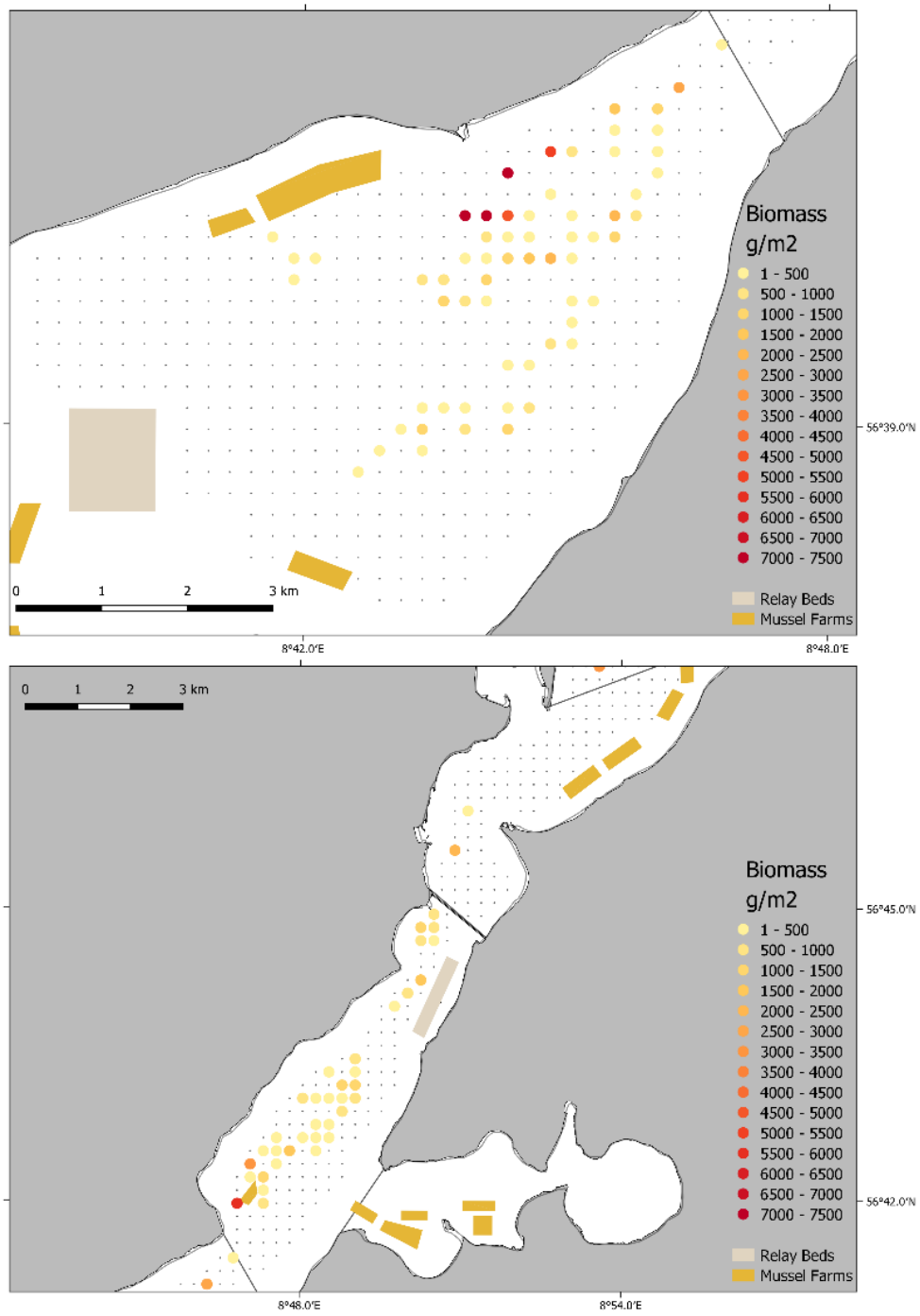


**Figure 4. Cockle biomass (g/m$^2$) in spring 2023: Kås Bredning (MO 9; top), Salling Sund Syd and Nord (Mo 11 and 13; bottom). Blue mussel relay beds (beige) and farms (yellow).**

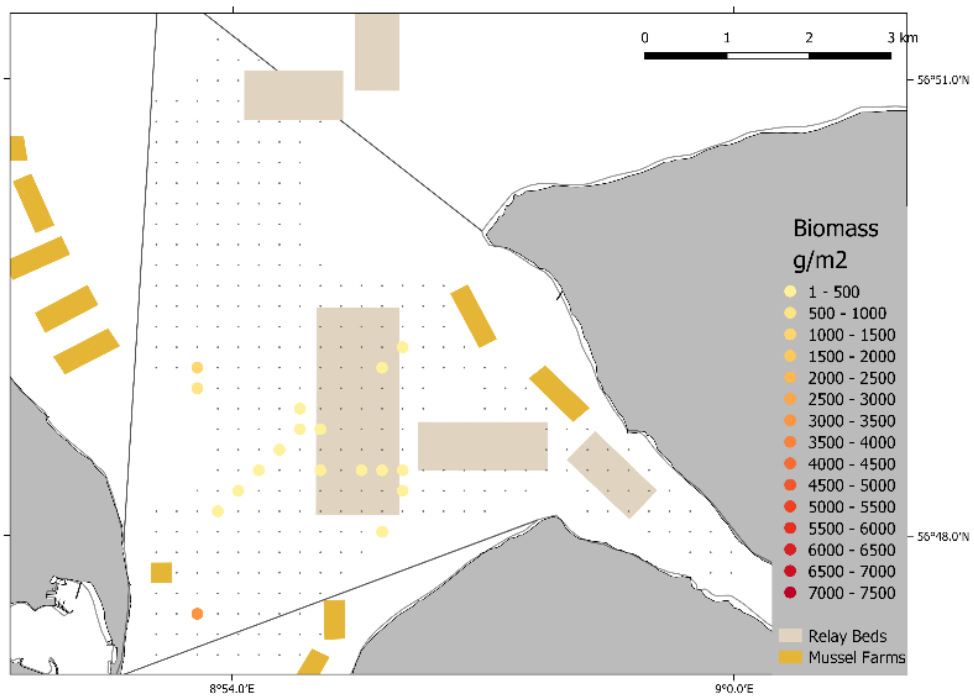


**Figure 4 (cont.). Cockle biomass (g/m$^2$) in spring 2023 in Sønder Bredning (MO 15). Blue mussel relay beds (beige) and farms (yellow).**

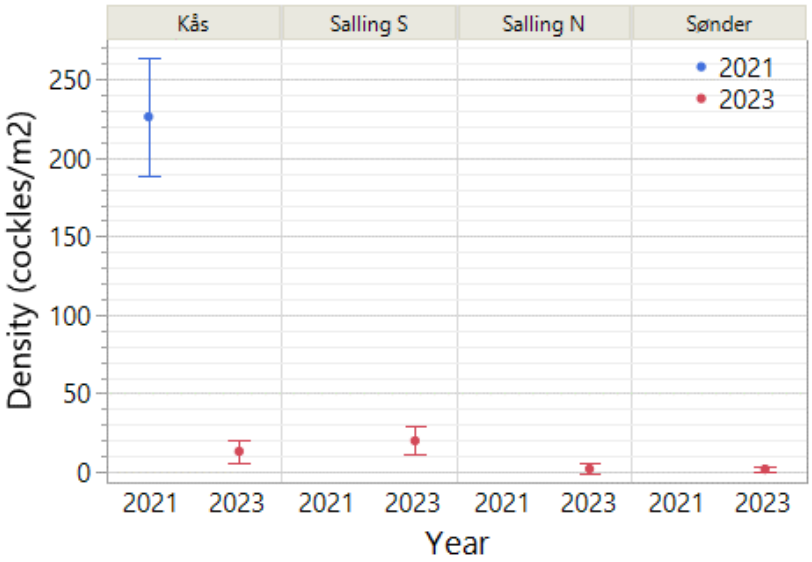


**Figure 5. Comparison of cockle density (cockles/m$^2$) in the spring 2021 and spring 2023 surveys. Cockle density was significantly higher in Kås Bredning in 2021 than in any of the areas surveyed in 2023. Error is 95% confidence interval of mean.**

**Table 4. Total cockle stock estimates (tonnes); density (cockles/m$^2$), biomass (g/m$^2$) from the 2023 DTU Aqua Surveys. Intervals are 95% confidence intervals of mean. N is number of stations.**

| | **Stock** (tonnes) | **N** | | **Density** (cockles/m$^2$) | **Biomass** (g/m$^2$) |
|---|---|---|---|---|---|
| Kås Bredning (9) | 4,075 (3,209 – 5,283) | 62 | Cockle beds | 100 (78 – 129) | 1,052 (828 – 1,363) |
| | | 474 | All | 13.0 (11.9 – 14.3) | 138 (126 – 151) |
| Salling Syd (11) | 1,750 (1,284 – 2,472) | 36 | Cockle beds | 79 (58 – 111) | 778 (571 – 1,099) |
| | | 143 | All | 20 (16.9 – 23.4) | 196 (167 – 232) |
| Salling Nord (13) | 181 (59 – 1,090) | 2 | Cockle beds | 105 (34 – 631) | 1,450 (470 – 8,720) |
| | | 112 | All | 1.9 (1.6 – 2.3) | 26 (22 – 31) |
| Sønder Bredning (15) | 553 (360 - 912) | 18 | Cockle beds | 33 (21 – 54) | 492 (320 – 811) |
| | | 348 | All | 1.7 (1.5 – 1.9) | 25 (23 – 28) |
| **Total** | 6,559 (5,505 – 7,900) | 118 | Cockle beds | 83 (70 – 100) | 889 (746 – 1,071) |
| | | 1077 | All | 9.1 (8.6 – 9.7) | 97.4 (91.9 – 103.5) |

Mean cockle density and biomass in all areas surveyed in spring 2023 were lower than 20 cockles/$m^2$ and 196 g/$m^2$ (Table 4 and Figure 5), but also significantly lower than in Kås Bredning in spring 2021 (226 cockles/$m^2$ and 914 g/$m^2$; Appendix 2). Even considering only the cockle beds (Table 4), density and biomass were still significantly low compared to Kås Bredning in spring 2021.

Total mortality (i.e. natural and fishing mortalities) in Kås Bredning estimated from the decrease in density (number of cockles/$m^2$) between 2021 and 2023 was 94%.

**Stock estimates**

Total cockle stock biomass in the four fishing areas surveyed in spring 2023 was estimated at only 6,559 tonnes (95% CI: 5,505 – 7,900; Table 4).

Harvestable biomass (Appendix 2) was the same as total biomass as all cockles sampled were larger than a minimum reference size of 16 mm shell width (see below; Notat jr. 21-1033607, Notat jnr. 22-1008192).

The majority of cockle biomass was found in Kås Bredning, while the other three fishing areas contained lower biomass (Table 4):

- Kås Bredning: 4,075 tonnes (95% CI: 3,209 – 5,283)
- Salling Sund Syd: 1,750 tonnes (95% CI: 1,284 – 2,472)
- Salling Sund Nord: 181 tonnes (95% CI: 59 – 1,090)
- Sønder Bredning: 553 tonnes (95% CI: 360 – 912).

Relative to historical landings, as well as to the 2021 survey of Kås Bredning, cockle biomass in spring 2023 in the four fishing areas surveyed is considered very low (Tables 1 and 4; Appendix 2 for a more detailed description). For comparison, the four areas surveyed produced mean landings of 6,572 tonnes/season corresponding to 86% of total landings since 2017-2018 (Table 1). While Kås Bredning alone in spring 2021 had a total biomass of 27,061 tonnes (95% CI: 23,941 – 30,182) and a harvestable biomass of 8,660 tonnes (95% CI: 7,662 – 9,838; revised relative to Notat jnr. 21-1033607).

**Cockle size**

In the four surveyed areas, all cockles were larger than a minimum reference size of 16 mm shell width (Figures 6; Figure A4 Appendix 2).

Even though no cockles smaller than the minimum reference size were observed, the shape of the histograms in Figure 6 (e.g. in Kås Bredning or Salling Sund Syd), suggests smaller cockles were likely present in the populations but at very low abundance.

Growth between the time of the survey in June 2023 and the start of the next fishing season in autumn will increase the size of cockles and will likely bring any cockles smaller but close to the minimum reference size into the harvestable fraction. Thus, the entire cockle biomass in the four surveyed areas at the time of the survey is assumed to be available to the fishery.


**Figure 6. Relative frequency distribution of cockle shell width (i.e. % each 1 mm size bin) in Kås Bredning (MO 9), Salling Sund Syd (MO 11), Salling Sund Syd (MO 13) and Sønder Bredning (MO 15) in June 2023 (weighed by cockle density, 49 stations, n = 849). Vertical dashed line is the minimum reference cockle size of 16 mm shell width.**

### Cockle age

Cockles in three of the surveyed areas, Kås Bredning, Salling Sund Syd and Salling Sund Nord, were mostly 4 years of age constituting from 80 to 99 % of the populations (Figure 7). Cockles in Sønder Bredning ranged in age from 2 to 5 years, but mainly were 4 and 5 years of age (Figure 7). Cockles with 2 or 3 years of age had low abundances, ca. 20 % in Kås Bredning and 27 % in Sønder Bredning, and much lower in Salling Sund Syd and Nord (Figure 7).

### Recruitment

In none of the areas surveyed were live cockle spat or juveniles observed (Figures 6 and 7), even on additional 40 stations in the area with highest density in northeast Kås Bredning that were sieved through a 2 mm mesh (Figure 3).

Considering the current size and age structure of cockles, together with observations in Kås Bredning in the 2021 survey (Notat jr. 21-1033607) and the very small and limited survey in 2022 (Notat jnr. 22-1008192), it is highly unlikely that significant cockle recruitment has occurred since 2019 in any of the four surveyed areas (Appendix 2).

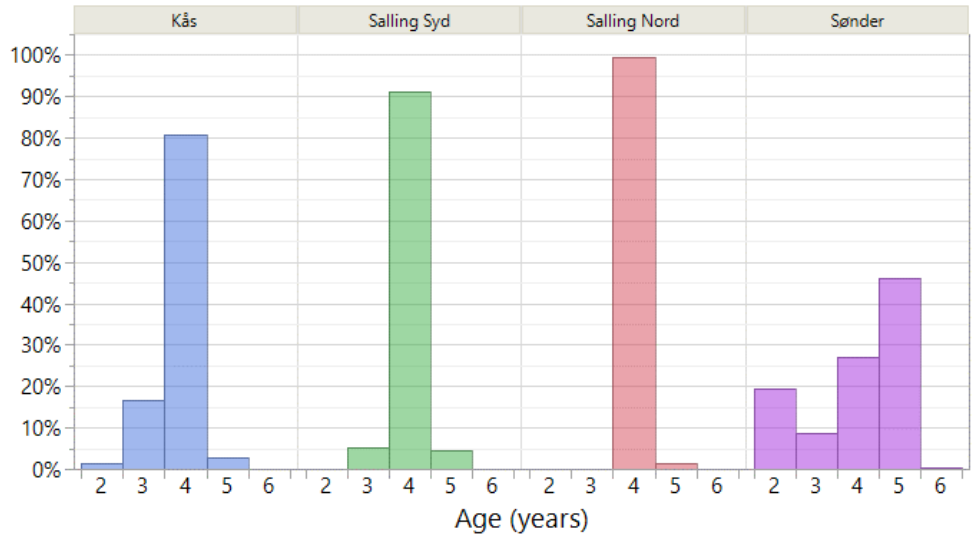


**Figure 7. Relative frequency distributions of age cohorts of cockles in the in Kås Bredning (MO 9), Salling Sund Syd (MO 11), Salling Sund Syd (MO 13) and Sønder Bredning (MO 15) in June 2023 (weighed by cockle density, 49 stations, n = 842).**

## 4. Considerations for the 2023-2024 season

### Landings in 2022-2023

In the last season, cockles were fished almost exclusively in three fishing areas (Table 1 and Figure 2), Kås Bredning (MO 9), Salling Sund Syd (MO 11) and Salling Sund Nord (MO 13).

Landings from the two main fishing areas were at historical low levels:

- In the main fishing area Kås Bredning were the lowest since 2017 at only 55% of mean landings.
- In the second most important fishing area Sønder Bredning were virtually zero.

High total landings in 2022-2023 (third highest since 2013) resulted from a small area with infrequent landings producing record high levels (Salling Sund Syd). The fishery mainly relied on beds fished for the third and second consecutive seasons, but with significantly lower landings, except in Salling Sund Syd (Table 3).

### Stock assessment 2023

The historically two most important fishing areas (Kås Bredning and Sønder Kås Bredning) and two important fishing areas of recent seasons (Salling Sund Syd and Nord) were surveyed. Surveyed areas in 2023 had a cockle stock estimate of only 6,559 tonnes while they were responsible for 86% of total landings since 2017-2018 at an average of 6,572 tonnes/season (Table 1).

Cockles occurred in previously fished cockle beds with few exceptions (Figure 3). Cockles were distributed at low density and biomass with only a few exceptions (Figure 4). No significant recruitment into cockle populations was observed in the four surveyed areas, possibly since 2019, and no juveniles or spat were observed.

Cockle stock estimates in the four surveyed areas (Table 4):

- All cockles were large enough to be available to the fishery.
- Harvestable biomass was thus equal to total biomass at only 6,559 tonnes (95% CI: 5,505 – 7.900).
    - Kås Bredning: 4,075 tonnes (95% CI: 3,209 – 5,283)
    - Salling Sund Syd: 1,750 tonnes (95% CI: 1,284 – 2,472)
    - Salling Sund Nord: 181 tonnes (95% CI: 59 – 1,090)
    - Sønder Bredning: 553 tonnes (95% CI: 360 – 912).

Cockle biomass in the four surveyed areas was significantly low considering past landings, fishing patterns and survey data (Tables 1 and 4):

- Total and harvestable biomass were almost equal to mean landings of 6,572 tonnes/season since 2017-2018 (Table 1).
- Mean landings per area since 2017-2018:
    - Kås Bredning: 4,517 tonnes (3,009 – 6,250)
    - Salling Sund Syd: 970 tonnes (0 – 5,068)
    - Salling Sund Nord: 243 tonnes (0 – 1,289)
    - Sønder Bredning: 842 tonnes (19 – 2,120).
- In the main fishing area Kås Bredning, cockle biomass in spring 2023 was only 15.1% of total biomass and 47.1% of harvestable biomass in spring 2021.
- In Salling Sund Syd, cockle biomass in spring 2023 although significant historically, is unlikely to support very significant landings (i.e. over ca. 1,000 tonnes) for a second consecutive season.

**Further considerations**

Knowledge on cockle populations and fishery in the Limfjorden is currently the most detailed and comprehensive in the history of the fishery to support establishing catch limits.

Status of cockle populations in surveyed areas before 2023-2024 season

- Low cockle biomass in spring 2023, except in Salling Sund Syd, and the lack of significant recruitment over several recent years is significant, considering past landings, fishing patterns and survey data.
- Due to the large size of cockles, harvestable biomass is equal to total biomass. All biomass is thus available to the fishery, but with no juvenile biomass to support future recruitment and fishing.
- Cockle biomass assessed in spring, as done in 2023, will change before the start of the following fishing season in autumn, reflecting a balance between natural mortality and cockle growth from late spring to early autumn (e.g. Notat jnr. 22-1008192).

Expected fishery behaviour in 2023-2024:

- In the four surveyed areas, the fishery can only rely on what remains from previously fished and ageing cockle populations, with expected lower catch rates than last season.
- The fishery may increase the area fished to compensate for low density and reduced catch rates in the four surveyed areas.
- The fishery may also find that cockle biomass is too low in some locations for fishing to be economically profitable.

*Alternative fishing areas:*

- The fishery may search and find significant cockle populations in non-surveyed areas to compensate for the low cockle abundance and low catch rates in the four surveyed areas in spring 2023.
- In the three seasons when both the two main fishing areas Kås Bredning and Sønder Bredning produced low landings, as expected in 2023-2024, landings from other areas were not always enough to avoid significantly below average landings (i.e. 2014-2015 and 2015-2016, Table 1).
- Of non-surveyed fishing areas, only Venø Bugt (MO 7 and 8) and Visby Bredning (MO 25) have provided significant landings since 2016 (Table 1).
- These three areas produced at most 2,582 tonnes in a single season, with a mean of 1,031 tonnes/season since 2017-2018 (Table 1).

*Total allowable catch (TAC):*

- A TAC should be a fraction of harvestable cockle biomass, itself normally a fraction of total biomass, for several reasons (e.g. Dare et al., 2004): ensure spawning biomass for the production of future recruits; with uncertain recruitment, the harvestable cockle biomass in one season may be the main or only fishable biomass the following season; and cockles have multiple ecosystem roles and services, other than just supporting a fishery (e.g. Carss et al., 2020).
- Allowable harvest ratios (catch/biomass) between 20 to 44%, commonly 33%, of the harvestable biomass have been used in several cockle fisheries in Europe (Dare et al. 2004; Hervas et al, 2008; Southall and Tully, 2014; MII and BIM, 2018; IFCA, 1992, 2017).
- A TAC for the 4 areas surveyed in the coming 2023-2024 season will thus be well below mean landings per season.
- With low biomass, use of lower harvest ratios improves the protection of spawning biomass contrary to the use of higher harvest ratios to sustain higher catches.
- Even without a TAC being enforced, cockle catches will be a fraction of total and harvestable biomass, as the fishery cannot remove all biomass for several reasons: cockle beds missed by the fishermen; density too low or shells too abundant to be profitable to fish; poor cockle condition or size too small for the processing industry. For instance, record high landings from Kås Bredning in 2021-2022 were 23.1% and 72.2% of total and harvestable biomass in spring 2021 (revised relative to Notat jnr. 21-1033607).

## 5. Catch recommendations for the Limfjorden cockle fishery in 2023-2024

In view of landing records, stock assessment observations, limitations, and uncertainties, as well as the reasoning described above, management of the Limfjorden cockle fishery in 2023-2024 must consider:

- It is possible the current cockle stock in the main fishing areas surveyed is overfished. The current status in the main fishing areas is of significant low biomass and no evidence of significant recruitment over several seasons.
- The fishery will struggle in the coming 2023-2024 season or even in the following season. Non-surveyed areas will be essential to sustain landings if they contain significant cockle populations, particularly Venø Bugt and Visby Bredning. However, record landings from non-surveyed areas may be required to maintain landings at or close to mean landings of recent seasons.
- Further biomass removal from surveyed areas may impact future recruitment. Cockle populations in different areas of the Limfjorden are reproductively interconnected (Hansen et al., 2023), and should constitute a single stock, despite reporting per administrative fishing areas (muslingeområder). Non-surveyed and non-fished areas potentially contain significant spawning biomass sources for recruitment in surveyed areas (Hansen et al., 2023), but its actual relevance cannot be answered with the current knowledge.
- Total biomass and spawning biomass in surveyed areas, which includes the two main fishing areas, may be below levels that ensure future recruitment, the ecosystem roles and services provided by cockles (e.g. water filtration, food for predators, etc), or even viable fishing. A difficult question must be asked: has biomass reached a limit to trigger a management decision to strongly reduce fishing mortality or even reached the lowest biomass at which fishing should or can occur? However, such biomass limit points/thresholds cannot be defined with the current available knowledge.
- There is no management plan specific to the Limfjorden cockle fishery, with pre-agreed upon decision-making mechanisms or actions with stakeholders when stock biomass or other indicators reach pre-defined limits or thresholds. Setting limit points/thresholds is a management decision that should consider the protection of future spawning potential; ecosystem services provided by cockles; and the required densities necessary for a commercially viable fishery (e.g. Shouthall and Tully, 2014).

Therefore, DTU Aqua recommends a very precautionary conservative approach for cockle fishing in the Limfjorden for the coming season 2023-2024.

DTU Aqua recommends applying a separate TAC in 2023-2024 for the four surveyed areas in spring 2023 (MO 9, 11, 13 and 15) to limit cockle biomass removal in what are deemed significantly depleted areas. A TAC for the four surveyed areas in 2023-2024 of 2,165 tonnes using a harvest ratio of 33%.

- Kås Bredning (MO 9): 1,345 tonnes
- Salling Sund Syd (MO 11): 578 tonnes

- Salling Sund Nord (MO 13): 60 tonnes
- Sønder Bredning (MO 15): 182 tonnes

However, management should strongly consider setting a lower TAC of only 1,312 tonnes, with a more conservative cautionary harvest ratio of 20% due to very low cockle abundance:

- Kås Bredning (MO 9): 815 tonnes
- Salling Sund Syd (MO 11): 350 tonnes
- Salling Sund Nord (MO 13): 36 tonnes
- Sønder Bredning (MO 15): 111 tonnes

A TAC established from either a 33% or 20% harvest ratio will result in the lowest landings from these four areas since 2013 (Table 1).

DTU Aqua cannot propose a TAC for non-surveyed areas in spring 2023, since the abundance and structure of cockle populations in these areas is currently unknown.

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## Appendix 1: Landings and fishing patterns

The location and area of distinguishable fished cockle beds in the 2022-2023 season were identified and separated from blue mussel beds based on black box and Elogs (BB - BlackBox R2, Anchor Lab, Copenhagen, described in Nielsen et al., 2021; Fiskeristyrelsen) and fishing information provided by Foreningen Muslingeerhvervet (FME). A fished cockle bed is defined here as an area encompassing dense fishing tracks and thus includes non-dredged areas between tracks and does not correspond to the areal impact from fishing, which originates from dredge tracks only.

The spatial distribution of fishing effort, defined here as the number of times 50 m cells were fished (i.e. cumulative area dredged inside a cell divided by the area of a 50 m cell), was variable within beds and between fishing areas (Table 3 and Figure A1). Generally, fishing effort decreased outwards from the core of the beds and was higher in Salling Sund Syd at 5.7 times and lower in Kås Bredning at 3.4 times and Salling Sund Nord at 2.6 times (Table 3 and Figure A1).

The fishery fished cockles by dredging multiple times significant fractions of the cockle beds that it considers more productive/abundant (Figure A1). Cockle beds were intensively fished by the fishery in 2022-2023 (Figure A1), with on average 78.6% of cockle beds surface area was dredged at least once: 83.6% in Kås Bredning, 88.2% in Salling Sund Syd and 56.7% in Salling Sund Nord (Table 3 and Figure A1).

The spatial distribution of cockle catches was estimated from daily landings of each fishing vessel that were proportionally attributed to each track according to track length, i.e. it infers catches from daily landings of individual boats and the spatial distribution of fishing effort (Figure A2). This approach assumes catch rates of individual vessels to be constant in any given day and whatever the location, which is not accurate as shown by the distribution of cockle abundance (e,g, section 3 this notat; Notat jnr. 22-1008192). Currently it is the only approach available to approximate the spatial distribution of cockle catches.

Cockle catches in 2022-2023 were variable within beds and between fishing areas (Figure A2). As with fishing effort, catches generally decreased outwards from the core of fished cockle beds (Figure A3). The most productive areas coincided with highest fishing effort with few differences (Figures A1 and A2). Most cockle catches originated from a small fraction of the total fished area, ca. a third of fished cells: 83.9% of catches came from 32.6% of fished cells, those cells with catches > 1,000 kg (excluding grey cells in Figure A2).

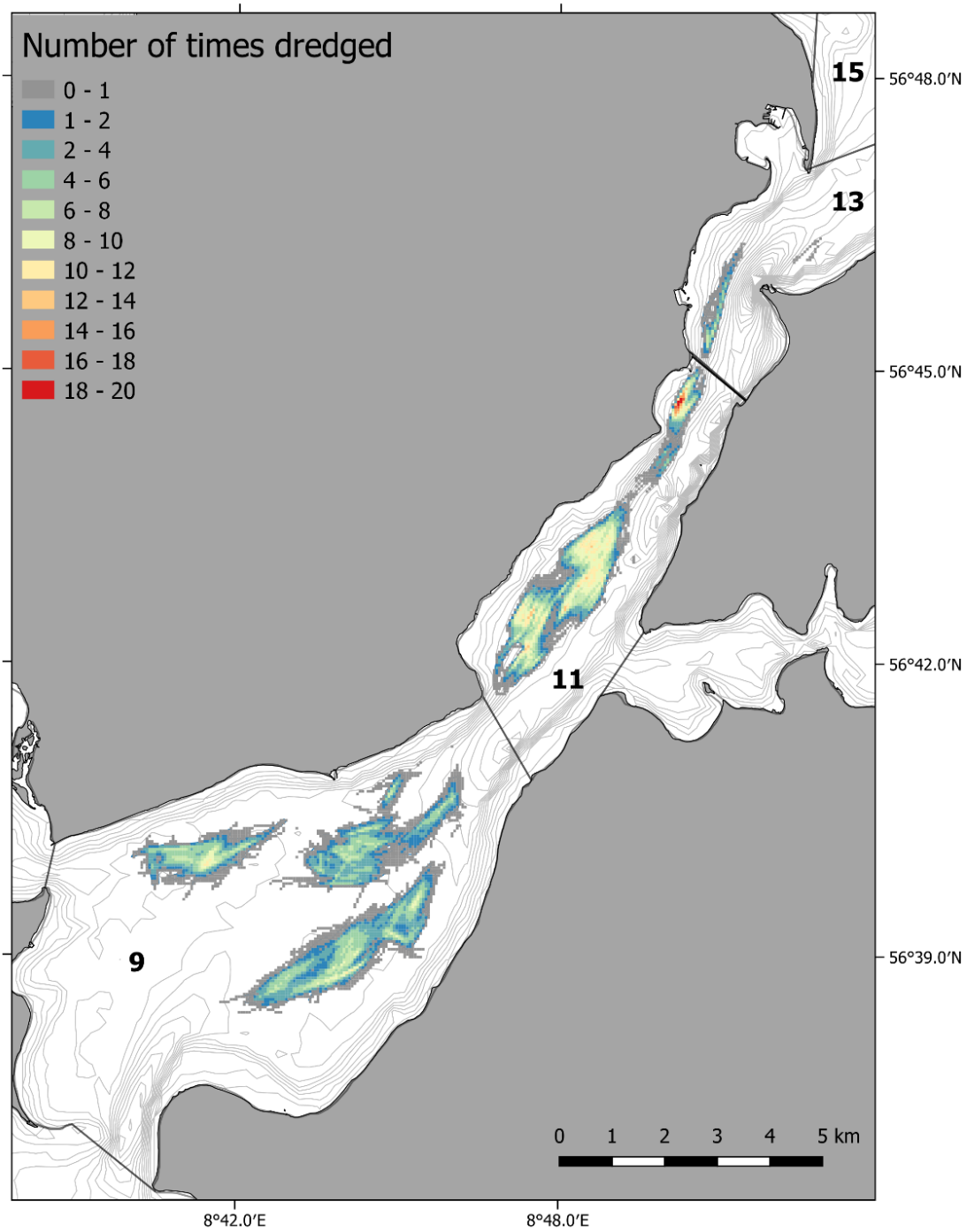


**Figure A1. Fishing effort in 2022-2023 in Kås Bredning, Salling Sund Syd and Nord. Defined as the number of times 50 m cells were dredged calculated from the dredged area per cell area. In grey cells that were dredged less than once in its entirety (i.e. dredged area smaller than cell area), in blues, greens and reds cells that were dredged more than once (i.e. dredged area larger than cell area).**

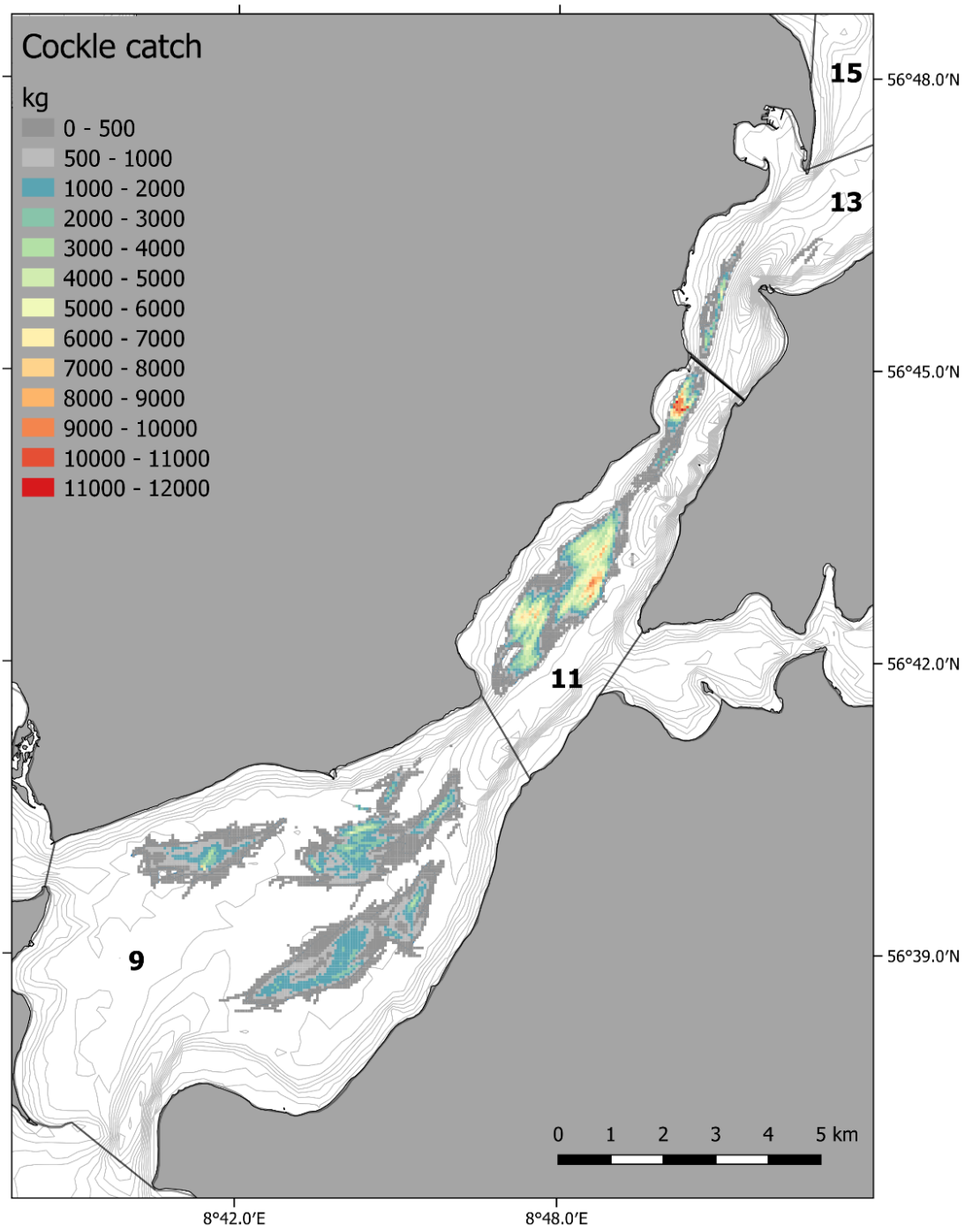


**Figure A2. Cockle catches (kg) in 2022-2023 in Kås Bredning, Salling Sund Syd and Salling Sund Nord. Catches were estimated from daily landings of each boat distributed proportionally to track length, i.e. assumes catch rate of each boat was constant in each day whatever the location. In dark and light grey, cells with less than 1000 kg catch.**

## Appendix 2: Spring 2023 survey

### Survey approach and design

The survey was designed to ensure a high sampling density of surveyed areas due to the aggregated nature of cockle beds (Figure A3). Covering 67.3 $km^2$ at 16 stations/$km^2$ to minimize the probably of missing significant beds and also improve the precision of survey estimates (e.g. Dare et al., 2004).

Total biomass stock estimates excluded all stations with no cockles, and biomass was estimated only for the area of cockle beds fitting an exponential distribution to biomass data due to its skewness. Overall precision of stock biomass estimates was 16% for the lower 95% confidence limit and 20% for the upper 95% confidence limit.

The survey collected samples from a total of 1077 stations on a 250 m grid (Figure A3) at depths greater than 3 m covering historical fished cockle grounds as defined from blackbox data (Figure A3). Some historical fished cockle beds may be missing, particularly in earlier seasons, due to difficulties in separating cockle fishing from blue mussel fishing in black box data.

A 0.1 $m^2$ Day grab (KC Denmark A/S; https://www.kc-denmark.dk/products/sediment-samplers/day-grab-/day-grab-1000-cm%C2%B2.aspx) was used to collect sediment to a depth that ensures 100% of the cockle population is sampled, similarly to the approach used in surveys of other European cockle fisheries (e.g. Dare et al., 2004).

Samples were sieved through a 10 mm mesh, which retains cockles larger than 14 mm shell length or 9 mm shell width, which at the time of the survey in spring is a size where cockles are at least one year old (i.e. have at least one winter). Smaller cockles will still be collected on the 10 mm mesh (Notat jr. 21-1033607, Notat jnr. 22-1008192), but at less than 100% efficiency.

At the end of the survey, 40 additional stations were sampled in Kås Bredning, based on information provided by fishermen and where density was found to be highest, and sieved with a 2 mm mesh to assess the presence of very small spat. All samples were sorted, counted, and weighed at DTU Aqua in Nykøbing Mors.

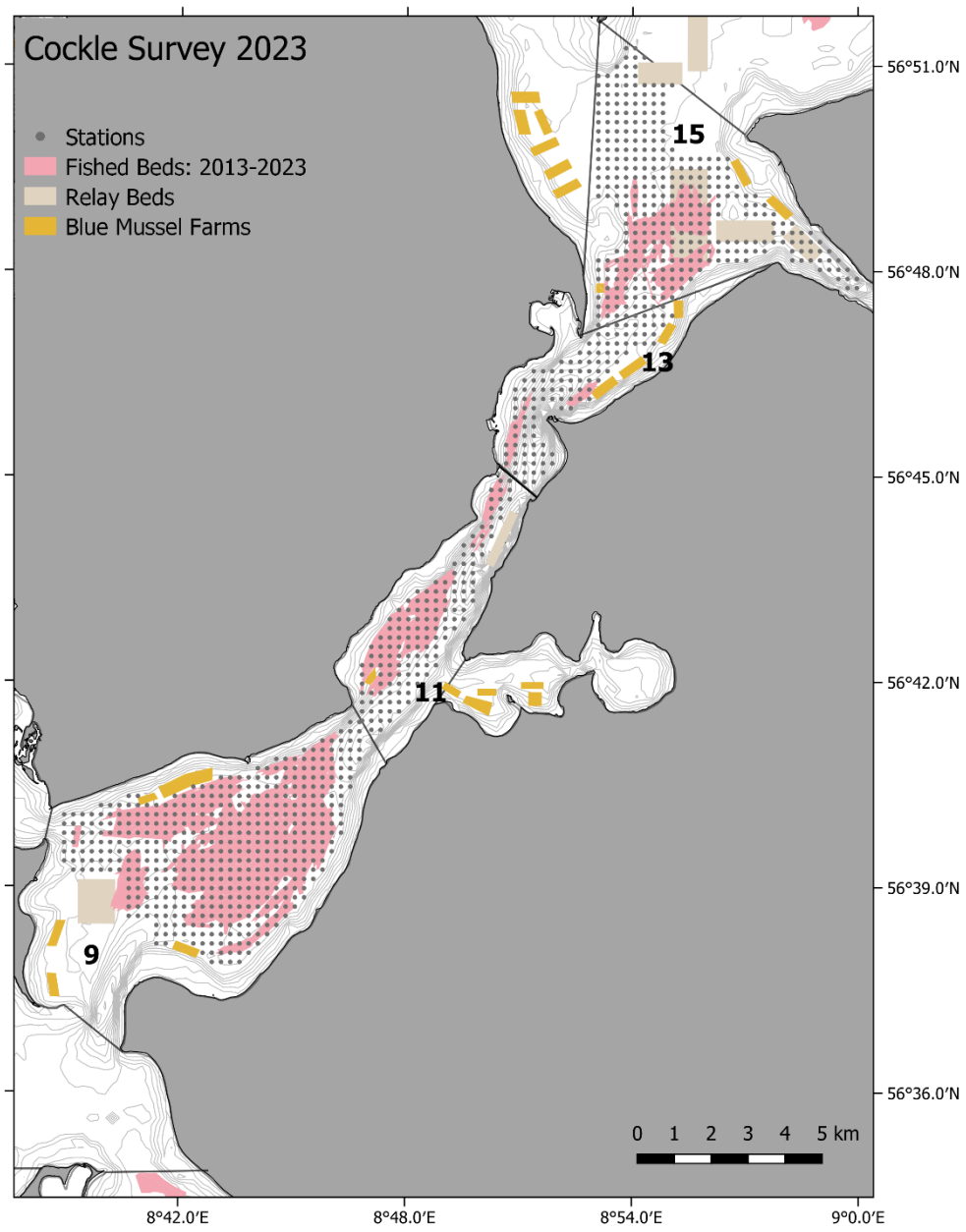


**Figure A3. The spring 2023 cockle survey sampled 1077 stations on a 250 m grid in main fishing areas: Kås Bredning (MO 9), Salling Sund Syd (MO 11), Salling Sund Nord (MO 13) and Sønder Bredning (MO 15). Shown are blue mussel relay beds (beige) and farms (yellow), and fished cockle beds since 2013 from blackbox data (pink).**

**Cockle abundance**

In Kås Bredning (Table 4; Figures 3, 4 and 5), mean cockle density and biomass were only 13 cockles/$m^2$ (95% CI: 11.9 – 14.3) and 138 g/$m^2$ (95% CI: 126 – 151). For comparison, in 2021 mean density was 226 cockles/$m^2$ (95% CI: 211 – 243) and biomass was 914 g/$m^2$ (95% CI: 851 – 984; revised relative to Notat jnr. 21-1033607).

In Salling Sund Syd, cockle density of 20 cockles/$m^2$ (95% CI: 17 – 23) and biomass of 196 g/$m^2$ (95% CI: 167 – 232) were also low and of the same order of magnitude as in Kås Bredning (Table 4; Figures 3 and 4).

In Salling Sund Nord (Table 4; Figures 3 and 4), cockle density and biomass were very low at only 1.9 cockles/$m^2$ (95% CI: 1.6 – 2.3) and 26 g/$m^2$ (95% CI: 22 – 31). Only two stations out of 112 had cockles, resulting in a large error in estimates (Table 4).

Sønder Bredning (Table 4; Figures 3 and 4), had also very low cockle density and biomass of only 1.9 cockles/$m^2$ (95% CI: 1.5 – 1.9) and biomass of 25 g/$m^2$ (95% CI: 23 – 28), with cockles also occurring within a blue mussel relay bed.

**Stock estimates**

The harvestable biomass is the fraction of the total biomass that is actually available to the fishery (CWSS, 2002; Dare et al., 2004; Imenson and van den Bergh, 2006; Floor et al., 2013; Southall and Tully, 2014; Cappel and Nimmo, 2023).

Harvestable biomass may be the fraction larger than a minimum size, be it a reference size, defined legally to ensure immature individuals are not fished, or operationally defined by the fishing gear or industry. Harvestable biomass may exclude a proportion of total biomass or fishing area to protect spawning biomass; minimize ecological impacts, e.g. ensuring a minimum supply of food requirements for bird populations and other ecosystems services provided by cockles; or even to ensure cockle density is high enough to be economically viable to fish.

In Kås Bredning, cockle total biomass in spring 2023 was only 442 tonnes lower than mean landings since 2017-2018 (Tables 1 and 4). Landings in the previous two seasons of 2022-2023 and 2021-2022 were 66% and 153% of spring 2023 cockle biomass, respectively (Table 1).

In Kås Bredning, cockle total biomass in spring 2023 was only 15.1% of total biomass and 47.1% of harvestable biomass in 2021 (respectively, 27,061,372 tonnes, 95% CI: 23,941 – 30,182 and 8,660 tonnes, 95% CI: 7,662 – 9,838; revised relative to Notat jnr. 21-1033607).

The three other fishing areas were not surveyed in 2021, however, relative to historical landings (Table 1) only Salling Sund Syd contained significant biomass (Table 4), albeit only 34.5% of landings in the last season 2022-2023. Cockle biomass in Salling Sund Nord and Sønder Bredning was only 14% and 26% respectively of landings in 2021-2022, the last season with significant landings from both areas (Table 1).

### Cockle size

A minimum reference size of 16 mm shell width (Figures A4 and 6) was used to define the size limit of the harvestable fraction in the Limfjorden (Notat jr. 21-1033607, Notat jnr. 22-1008192). European cockle fisheries commonly use minimum legal or reference sizes between 14 to 22 mm shell width, to protect spawning potential and ensure a significant proportion of cockles reach maturity and reproduce (e.g. Dare et al. 2004; Southall and Tully, 2014; Hervas et al, 2008).

The size of all cockles in 49 stations were measured, corresponding to 78.4% of all cockles collected in the four surveyed areas.

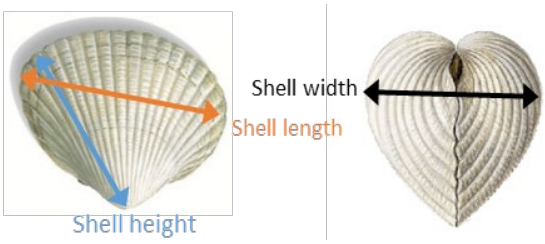


**Figure A4. The three dimensions used to measure cockle shells: shell height, length, and width. Normally, minimum sizes refer to shell width or length.**

Relative to previous seasons cockle shell width in Kås Bredning (MO 9) increased from 14.7 mm (±0.06 mm, 95%CI, n = 6630) in June 2021, to 16.4 mm (±0.2 mm, 95%CI, n = 567) in April 2022 (Notat jnr. 22-1008192), and to 20.6 mm (±0.2 mm, 95%CI, n = 573) in June 2023.

Cockle shell width was 21.8 mm (±0.3 mm, 95%CI, n = 198) in Salling Sund Syd (MO 11), 22.8 mm (±0.9 mm, 95%CI, n = 21) in Salling Sund Nord (MO13) and 24.2 mm (±0.5 mm, 95%CI, n = 57) in Sønder Bredning (MO 15).

Cockle shell width was different between surveyed areas (ANOVA, $F(2, 827) = 30.39$, $p < 0.0001$), excluding Salling Sund Nord due to its small sample size (n = 21), increasing in size from Kås Bredning to Salling Sund Syd and to Sønder Bredning (post-hoc Tukey-HSD, $p < 0.0003$ for all).

### Cockle age

Cockles were aged based on the presence of annual winter lines on the shell surfaced (e.g. Richardson, 1980; Jones and Baxter, 1987) on 49 stations in the four surveyed areas (n = 842).

Cockles in the Limfjorden commonly present disturbed growth based on the experience of DTU Aqua over recent year ageing cockles from several basins: e.g. Nissum Bredning, Venø Bugt, Kås Bredning, Salling Sund, Sønder Bredning and Visby Bredning.

Cockles sampled in spring 2023 often presented a disturbed growth, which caused increased ageing uncertainty with age, particularly at ages of 4 and 5 years old. This is unavoidable as the precision of ageing is increasingly affected at older ages by the presence of secondary non-annual lines linked to reductions or disturbances in growth within a given year (e.g. Richardson, 1980; Ramon, 2003).

Nevertheless, the presence of similar growth patterns (i.e. same sequence of large-small-large growth increments and the occurrence of secondary non-annual lines at the same location within that sequence) provided assurances on the overall age structures obtained in the four surveyed areas.

**Recruitment**

Recruitment is defined here as one year old cockles that are assumed to be mature (e.g. Dabouineau and Ponsero, 2011), i.e. cockles that have gone though one winter after settlement, which for spring 2023 would be cockles settled the previous spring-summer of 2022. This definition is different to the use of a minimum reference size of 16 mm shell length to define the harvestable fraction of the total cockle biomass (Notat jr. 21-1033607; Notat jnr. 22-1008192), as one year old cockles can be smaller or larger than 16 mm shell width.