DTU Aqua
National Institute of Aquatic Resources

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Pedro S. Freitas (Ed.), Henrik Baktoft, Elliot J. Brown, Mads Christoffersen, Josefine Egekvist, Jordan P. Feekings, Rikke P. Frandsen, Alexandros Kokkalis, Martin L. Kristensen, Martin H. Larsen, Mette K. Schiønning, Josianne G. Støttrup, Jon C. Svendsen, and Jens K. Petersen

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Cover photo: Surveying European lobster (*Homarus gammarus*) distribution in the Limfjorden. Photo: Pedro S. Freitas

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Preface

This report presents the results from the project “Bæredygtigt hummerfiskeri i Limfjorden” (ref. nr. 33113-B-19-137), which received financial support from the European Maritime and Fisheries Fund and the Danish Ministry for Food, Agriculture and Fisheries (“Ministeriet for Fødevarer, Landbrug og Fiskeri”) program “Hav- og fiskeriudvikling”.

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Two of the chapters in the report are in Danish. Non-Danish speakers are referred to the extensive English summary in the beginning of the report for an abstract of these chapters.

Nykøbing Mors, March 2023

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Den Europæiske Union
Den Europæiske Hav- og Fiskerifond

HAV & FISK

Content

Dansk resumé

Fiskeriet af europæisk hummer i Limfjorden er det vigtigste danske hummerfiskeri med årlige landinger på ca. 24 tons til en værdi af 4,4 mio.kr. pr. år og har stået for 63% af alle danske hummerlandinger siden 2010. Hummerfiskeriet er steget siden slutningen af 2000'erne og er nu lokalt økonomisk og kulturelt vigtigt som et kommercielt - men også i betydelig grad rekreativt - fiskeri.

Fiskeriet er et såkaldt datafattigt fiskeri (ICES kategori 5), hvor der kun foreligger oplysninger om officielle landinger og antallet af aktive fartøjer i erhvervsfiskeriet. Den manglende viden om fiskeriet og hummerens biologi i Limfjorden udgør en risiko for, at ressourcen ikke bliver bæredygtigt forvaltet. Selv om der ikke foreligger data, der understøtter, at bestanden er overfisket, eller at fiskeridødeligheden er for høj, forventes en evt. genopretning efter et ikke-bæredygtigt fiskeri at tage flere år som følge af den langsomme vækst og sene modenhed hos den europæiske hummer. Der er således ikke noget ønske blandt interessenterne om at bestanden kollapser, og der er et udbredt ønske hos interessenterne om en bæredygtig forvaltning af hummerfiskeriet i Limfjorden.

Formålet med projektet var således at igangsætte undersøgelser af hummerbestanden og fiskeriet i Limfjorden for at understøtte en bæredygtig forvaltning.

Interessentinddragelse skete gennem to offentlige møder for alle interesserede ved projektets start og afslutning samt gennem nedsættelse af en rådgivende følgegruppe med repræsentanter for interessenter til drøftelser om projektets resultater og forslag til forvaltningsværktøjer (kapitel 9).

Kapitel 2 omhandler fiskeritrykket i erhvervs- og fritidsfiskeriet og omfatter spørgeskemaundersøgelse, landingsstatistik og en undersøgelse foretaget gennem Danmarks Statistik:

Spørgeskemaer blev sendt til interessenter og omhandlede oplysninger om fiskepladser, deres beliggenhed og kvalitet samt om hummerbestandens seneste udvikling og status. Ifølge spørgeskemaresultaterne foregår det kommercielle fiskeri hovedsageligt med tejner, ruser eller kinaruser, mens fritidsfiskere også bruger garn. Dertil kommer dykkere, der indsamler hummer. Fiskeriet foregår normalt på dybder fra 2-8 m, hovedsageligt i den vestlige og centrale del af Limfjorden og betragtes som bedst i maj-juni og september-oktober.

Landingsstatistikken viser en stigning i kommercielle landinger fra midten af 2000'erne med en samtidig stigning i antallet af fartøjer, der lander hummer fra Limfjorden. Landingerne er højest i maj-juni og september-oktober. I de områder uden for Limfjorden, hvor der ikke er sæsonbestemte fiskerirestriktioner, er landingerne relativt jævnt fordelt over månederne maj til december, men topper i sommermånederne. Derimod er der i Limfjorden i september større landinger umiddelbart efter sæsonåbningen af fiskeriet. Data fra nøglefiskere (fritidsfiskeri) i Limfjorden for fiskeri med standard ruser og net viste, at flest hummer blev fanget i Venø-Kås Bredning-området, hvilket understøtter resultater fra tidligere monitering af DTU Aqua. Antallet af hummere, der blev fanget pr. fiskeri, var generelt lavt og konstant hele året i det rekreative fiskeri. Der foreligger ingen data om dykkernes fangster.

Resultaterne fra Danmarks Statistiks undersøgelser er baseret på svar fra omkring 1500 respondenter med fritidsfiskerlicenser til passive fiskeredskaber og omkring 1600 lystfiskere (omfatter dykkere) hvert halve år over en periode på to år. Fritidsfiskere rapporterede op til 40 fisketure (to tilfælde), størstedelen mellem 1 og 10 fisketure og tilsyneladende højere fiskeriaktivitet i 2020 end i 2021. Antallet af hummere fanget varierede mellem 1 og 4 hummere pr. fisketur. Blandt dykkere (lystfiskere) varierede det rapporterede antal fisketure fra 1 til 6 i 2020 og fra 1 til 30 i 2021. Antallet af hummere fanget på hver fisketur varierede mellem 1 og 6 hummere, hvor nogle fangede et stort antal hummere i løbet af en sæson på flere fisketure.

Kapitel 3 rapporterer et indeks (RPUE) baseret på landingsindsats pr. enhed (LPUE), der korrigerer for temperaturens effekt på hummeraktivitet og fangstbarhed, som en forbedret og mere robust indikator for ændringer i hummerbestanden i Limfjorden:

RPUE identificerede to perioder med reduceret hummerforekomster mellem 2011 og 2014 og mellem 2019 og 2021 og med øget forekomst i 2015 og 2022, sidstnævnte var usædvanligt høj. Fald i forekomsten udtrykt som RPUE tolkes som udtryk for perioder, hvor rekruttering og vækst ikke var i stand til at kompensere for fiskeridødeligheden, mens god rekruttering til fiskeriet resulterer i højere forekomst og fangster, som det blev observeret, da rekruttering af en stærk kohorte resulterede i rekordlandinger i 2022 (kapitel 4).

Kapitel 4 beskriver størrelsen af hummere i Limfjorden gennem størrelsesbaserede indikatorer (middellængde, størrelse ved første fangst og den øvre 95 percentil) i fangster, men også af den landede fraktion:

Størrelsen af hummere blev sammenlignet mellem et beskyttet område med lav fiskeridødelighed og fiskede områder. Den nuværende størrelsesstruktur (dvs. foråret 2022) på tværs af den vestlige og centrale Limfjord blev vurderet, og væksten af en kohorte og dens rekruttering til fiskeriet i 2022 blev evalueret. Der blev opnået allometriske relationer, der er specifikke for Limfjordens hummerbestand, og som gør det muligt at konvertere mellem rygskjoldslængde, totallængde og vægt.

Hummerbestanden i Limfjorden har en komprimeret størrelsesstruktur med afkortede størrelsesfordelinger og lav forekomst af større størrelser. Der blev observeret betydeligt større størrelser i det beskyttede område end i tre fiskede områder, hvor rygskjoldslængde i fiskede områder var 7-10 mm kortere hos hunner og 11-16 mm hos hanner end i det beskyttede område. Kun i det beskyttede område var den gennemsnitlige fangstlængde større end mindstemålet (MLS) på 87 mm. I det beskyttede område var 56% af fangsten større end MLS, mens det i de fiskede områder kun var 9-24%.

På baggrund af fangstrapporter indsamlet i foråret 2022 fra fem bassiner, spændende fra Nissum Bredning i vest til Løgstør Bredning i nordøst kunne det dokumenteres, at kun 28% af alle hunner, der blev fanget, kunne landes lovligt, mens resten var undermål eller æg bærende hummere. I 50% af landingerne var skjoldlængden kun 5 mm længere end MLS på 87 mm, hvilket højst svarer til et halvt eller et skalskifte, mens den gennemsnitlige landingslængde kun var 7 mm længere end MLS, hvilket højst svarer til et eller to skalskifte efter MLS er nået.

Det tog ca. to år for en kohorte af hummere på 60 mm længde af rygskjoldet at nå MLS, hvilket tyder på, at hummere i Limfjorden er fem-seks år om at nå MLS. Vækst i forskellige årstider indikerer at skalskifte for denne størrelsesgruppe sker på forskellige tidspunkter af året og ikke kun i slutningen af foråret og om sommeren. Skalskiftefrekvensen og væksten ved størrelser tæt på MLS indikerer skalskifte mindst en gang om året, mens der i mindre hummere kan være to skalskift på ét år for at kunne nå en vækst på 16 mm på ét år. I Limfjorden følger hunhummere tæt på MLS således en etårig reproduktionscyklus og ikke en 2-årig reproduktionscyklus (kapitel 5).

Rekrutteringen fra en meget stor kohorte forklarer de ekstraordinære landinger i 2022, næsten det dobbelte af 2021 og 67% over de gennemsnitlige årlige landinger siden 2015. Rekordlandingerne blev opnået i efteråret 2022 i alle måneder fra september til december (kapitel 3).

Kapitel 5 omhandler en vurdering af størrelsen ved kønsmodenhed for hummere i Limfjorden og en sammenligning af hunhummers reproduktionspotentiale mellem flere fiskepladser og et beskyttet område:

Europæiske hummere viste sig at følge en årlig reproduktionscyklus og størrelse ved første kønsmodenhed, defineret som når 50% af hunnerne er kønsmodne, var 95,6 ±1,1 mm rygskjoldlængde og dermed 8,6 mm større end MLS. Ved MLS var kun 26% af hunnerne kønsmodne, og i 2022 var 68% af landingerne i størrelser, der var mindre end størrelsen ved første kønsmodenhed. Det skal bemærkes, at den metode, der er mest anvendt til at vurdere kønsmodenhed hos hunner, og som anbefales af ICES, fører til konservative estimater af størrelse ved første kønsmodenhed, uden at vi dog kan kvantificere dette.

Reproduktionspotentialet i Limfjorden var 74-86% lavere i fiskede områder end i et lille, beskyttet område, selvom hummerne i det beskyttede område stadig var udsat for en vis fiskeridødelighed ved vandring ud af det beskyttede område. Ægproduktionen er hovedsagelig afhængig af små hummere, idet 32-41% af ægproduktionen kommer fra størrelser, der er mindre end MLS i fiskede områder. Til sammenligning gælder det kun for 9% i det beskyttede område. 50% af ægproduktionen i Limfjorden stammer fra hummere mindre end 91-96 mm svarende til den gennemsnitlige længde af landede hunner (kapitel 3) og kun 4-9 mm større end MLS. Denne undersøgelse kunne imidlertid ikke fastslå, om de nuværende ægproduktionsniveauer i Limfjorden er tilstrækkelige til at opretholde rekruttering og fornyelse af hummerbestanden.

Kapitel 6 undersøger habitatpræferencer og udbredelse af den europæiske hummer i Limfjorden:

En stratificeret tilfældig feltprøvetagningskampagne blev brugt som input til modeller af hummer bestandstæthed i forhold til to vigtige fysiske miljøforhold: Dybde og substrattype. Dybde har en positiv effekt på hummerforekomsten, selv i det begrænsede dybdeinterval i den lavvandede Limfjorden. Desuden var stenede levesteder det bedste levested i forhold til sand, mudder og blandede underlag.

Den udviklede habitatmodel var generelt i overensstemmelse med indsamlede feltdata, men kunne ikke pålideligt forudsige hummerforekomst under nye forhold, når de blev testet i tilfældig krydsvalidering. Derfor kunne der ikke foretages rumlige forudsigelser i form af kort over potentielle levesteder.

Kapitel 7 rapporterer om hummers bevægelsesadfærd i Limfjorden ud fra to tilgange: en større fangst-genfangstundersøgelse i den vestlige og centrale del af Limfjorden og en mindre akustisk telemetriundersøgelse ved Livø stenrev:

Hummere bevægede sig generelt kun korte distancer (få 100'ere til 1000 m) mellem fangst- og genfangststeder, ofte over kun få uger, hvilket viser kraftig stedbundenhed. Der blev dog også observeret større bevægelser mellem fiskepladser og bassiner på mindst 4-12 km et til to år efter mærkningen. En akustisk telemetriundersøgelse fra slutningen af august til begyndelsen af januar viste stærk stedbundenhed med et ”hjemmeområde” (95% udnyttelsesfordeling) svarende til, hvad der er fundet andre steder i Europa, og spændende fra 100 m^2 til 2-30.000's m^2. Den daglige bevægelse var generelt et par hundrede meter, lejlighedsvis mere end 500 m og op til ca. 2 km, hvor hanner rejste længere afstande om dagen end hunner. Hummeraktiviteten var generelt højere om natten, men med betydelig individuel variation. Den tilbagelagte afstand faldt i slutningen af efteråret og vinteren, når temperaturen faldt til under 10°C.

Kapitel 8 estimerer effektiviteten af de mest almindelige typer redskaber, der anvendes til at fange hummer i Limfjorden:

Åleruse blev valgt som reference redskab, da åleruser kan bruges af både større og mindre både og er velkendt af alle erhvervs- og fritidsfiskere i området. Rigning med 3 åleruser pr. streng passede til de fartøjer, der deltog i forsøgsfiskeriet. Antallet af hummertejner, net og multitejner, der er nødvendige for at matche fangsten af hummer i 3 åleruser, blev bestemt. Fangsteffektiviteten var betydeligt højere i strengene med 4 multitejner end i strenge med 3 åleruser. Ingen af de andre redskaber adskilte sig væsentligt fra effektiviteten af åleruser, men uanset hvad bruger vi middelværdierne til at kalibrere fangsteffektiviteten i forskellige fiskeredskaber.

Vi anslår således fangsterne af lovlige hummere (dvs. større end MLS på 87 mm rygskjoldslængde og eksklusive æg bærende hunner) i multitejner til 2,1 (1,38-3,45) som svarende til fangsten i 3 åleruser. Som et enkeltstående redskab er hummertejner de mindst effektive. Der skal 9,7 (6,29-16,64) hummertejner til at opnå det samme antal lovlige hummere som 3 åleruser. Garn og toggergarn er omtrent lige effektive, når det kommer til at fange lovlige hummere, og for disse redskaber tager det henholdsvis 2,3 (1,50-3,51) og 2,3 (1,24-6,52) garn at fange et antal lovlige hummere, der svarer til fangsten i 3 åleruser.

I perioden fra 13/5 2021 til 25/6 2021 gennemførte vi i alt syv hele fiskedage med en samlet fangst på 1887 hummere, hvoraf 368 individer svarende til ca. 150 kg var over MLS. Med andre ord var i gennemsnit 80% af de fangede hummere under mindstemålet. Den høje andel af undermålshummer i fangsterne var overraskende og understreger betydningen af at øge selektivitet for størrelse i fiskeriet. De redskaber, der blev anvendt i forsøgsfiskeriet, følger retningslinjerne for redskaber i den gældende lovgivning. Derfor findes der i øjeblikket ingen anordninger, der kan forbedre selektivitet af hummere og dermed reducere andelen af hummere under MLS i fangsten.

I hummerfiskerier i bl.a. Norge og Sverige anvendes alene hummertejner og i disse er der krav om, at der skal være udslipshuller, der sikrer, at størstedelen af hummerne under MLS kan slippe ud af redskabet. I juni 2022 gennemførte vi derfor et forsøg, hvor vi testede effektiviteten af sådanne udslipshuller i multitejnerne. På trods af multitejnernes bløde sider, demonstrerede vi at udslipshuller er en effektiv metode til at øge udslippet af undermåls-hummer.

Kapitel 9 indeholder anbefalinger til reguleringsmuligheder, der kan indgå i den fremtidige forvaltning af hummerfiskeriet i Limfjorden:

Anbefalingerne er alene DTU Aquas anbefalinger, men er blevet til gennem diskussioner i følgegruppen og i diskussioner med interesserede ved åbne møder ved projektets start og afslutning. Anbefalingerne falder i tre kategorier og ligger udover den allerede eksisterende regulering på området, som der ikke er taget stilling til: Generel fiskeriforvaltning, regulering af redskaber og andre typer forvaltningsværktøjer. De generelle anbefalinger omfatter: a) Det bør udelukkende være tilladt at lande hele hummer, b) der skal ske en harmonisering af regler indenfor og udenfor Limfjorden, c) der må ikke ske udsætning af redskaber før fiskerisæsonen starter og d) loft over landinger i fritidsfiskeriet. Anbefalingerne vedrørende redskaber omfatter: e) forbud mod brug af nedgarn i hummerfiskeriet; f) kinaruser skal defineres som selvstændigt redskab med fast dimensioner, og g) flugthuller i kinaruser, ruser og tejner skal være obligatorisk. Derudover bliver det foreslået at igangsætte programmer til dataindsamling for at sikre bedre viden til forvaltning af bestanden samt overveje muligheden for brug af lukkede områder.

English summary

The Limfjorden European lobster fishery is the main Danish lobster fishery with landings of ca. 24 tons with a value of 4.4 Mio.kr. per year and is responsible for 63% of all Danish lobster landings since 2010. Lobster fishing increased since late 2000's and is now locally economically and culturally important as a commercial but also a significant recreational fishery.

The fishery is a data poor fishery (ICES Category 5), with only information available on official landings and the number of active vessels in the commercial fishery, and anecdotal reports of IUU fishing (illegal, unreported and unregulated). The lack of knowledge on the fishery and lobster biology in the Limfjorden poses a risk of the resource is not being sustainably fished and managed. Although there is no data supporting that the stock is overfished or that fishing mortality is too high, given the slow growth and late maturity of the European lobster, recovery from unsustainable fishing or overfished status is expected to take several years. There is thus no wish amongst stakeholders to reach a collapse of the population and there is a broad stakeholder wish for the sustainable management of the lobster fishery in the Limfjorden.

The aim of the project was thus to initiate the study of the lobster population and fishery in the Limfjorden to support its sustainable management and regulation.

The project promoted stakeholder participation and outreach through two open meetings and through the establishment of an advisory group with stakeholder representatives for discussions about the status and concerns regarding the fishery (Chapter 9).

Chapter 2 reports at fishing pressure in the commercial and recreation fisheries:

Questionnaires disseminated to the stakeholder's produced information on lobster fishing grounds, its location and quality, as well as on the recent evolution and status of the lobster population. According to questionnaire results, the commercial fishery is mainly conducted using pots or fyke nets including multi-pots ("kinaruser"), while recreational fishermen use also gillnets, except snorkel divers. The fishery usually takes place at depths from 2 to 8 m, mainly in the western and central Limfjorden. Fishing is considered best during May-June and September-October.

Landings statistics show an increase in commercial landings from mid-2000's, with a concurrent increase in the number of vessels landing lobsters from the Limfjorden. Landings were highest during May-June and September-October. In the areas outside the Limfjorden where there are no seasonal fishing restrictions, landings are relatively evenly distributed over the months May to December, topping in the summer months. In contrast, higher landings occur in September in the Limfjorden after the fishing season has opened. The yearly fishing surveys conducted by DTU Aqua showed increases in lobster catches from 2007 in the Venø-Kås Bredning area. Data from key fishermen database in the recreational fishery using fykenets and gillnets also showed that most lobsters were caught in the Venø-Kås Bredning area. The number of lobsters caught per fishing event was generally low and consistent throughout the year in the recreational fishery. No data was available on the catches by the snorkel fishers.

Results from "Danmarks Statistik" surveys are based on responses from around 1500 respondents with recreational "fritidsfisker" licenses using passive gears and around 1600 anglers each half year over a period of two years. Recreational fishermen reported up to 40 fishing events (two cases), the majority between 1 and 10 fishing events and apparently higher fishing activity in 2020 than in 2021. The number of lobsters caught in each fishing event varied between 1 and 4 lobsters per fishing trip. Among snorkel divers the reported number of fishing trips varied from 1 to 6 in 2020 and from 1 to 30 in 2021. The number of lobsters caught in each fishing trip varied between 1 and 6 lobsters, with some catching a good number of lobsters during a season in multiple fishing trips.

Chapter 3 reports an index (RPUE) based on landings-per-unit effort (LPUE), correcting for the effect of temperature on lobster activity and catchability, as an improved and more robust indicator of changes in the abundance of the lobster population in the Limfjorden:

RPUE indicated two clear negative periods of reduced lobster abundance between 2011 and 2014 and between 2019 and 2021, and two maxima with increased abundance in 2015 and 2022, the latter exceptionally high. Decreases in abundance are interpreted to reflect periods when recruitment and growth were unable to compensate for fishing mortality. Good recruitment into the fishery result in higher abundance and catches, as observed when recruitment of a strong juvenile cohort resulted in record landings in 2022 (Chapter 4).

Chapter 4 reports the size structure of lobsters in the Limfjorden through size-based indicators (SBI mean length, size at first capture and the upper 95th percentile) of catches but also of the landed fraction. Lobster size was compared between a protected area with no or low fishing mortality and fished areas; the current size structure (i.e. spring 2022) across the western and central Limfjorden was assessed; and the growth of a juvenile cohort and its recruitment into the fishery in 2022 was evaluated. Allometric relationships specific to the Limfjorden lobster population were obtained that easily permit to convert between carapace length, total length and weight measurements.

The Limfjorden lobster populations showed a significantly compressed size structure with truncated size distributions and a reduction in the abundance of larger sizes. Significantly larger sizes were observed in the protected area than in three fished areas, with carapace length shorter in fished areas by 7 to 10 mm in females and 11 to 16 mm in males. Only in the protected area was mean length of catch longer than minimum landing size (MLS). In the protected area, 56% of the catch was in the landed fraction while in the fished areas only between 9% to 24%.

The current lobster size structure in the Limfjorden in spring 2022 was obtained from five basins, ranging from Nissum Bredning in the west to Løgstør Bredning in the northeast. 28% of all lobsters caught constituted landings, with the remainder being undersized or ovigerous female lobsters. The size at which 50% of landings were obtained was only 5 mm longer than the MLS of 87 mm, corresponding at most to half or one moult increment. The mean length of landings was only 7 mm longer than MLS, corresponding at most to one or two moult increments after MLS.

Growth of a juvenile cohort took approx. two years for lobsters of 60 mm carapace length (CL) to reach the MLS of 87 mm, which suggest that lobsters in the Limfjorden take five or six years to reach MLS. Growth between different seasons indicated moulting at this size occurs at different times of the year and not just in late spring and summer. The moulting frequency and growth increment at sizes close to MLS indicate moulting at least once a year, while at smaller lengths double moulting must occur to account for 16 mm in growth in a year. Thus, in the Limfjorden female lobsters close to MLS follow a one-year reproductive cycle and not a 2-year reproductive cycle (Chapter 5).

The recruitment of this juvenile cohort explains the exceptional landings obtained in 2022, almost double of 2021 and 67% above mean annual landings since 2015, and the record landings obtained during autumn of 2022 in all months from September to December (Chapter 3).

Chapter 5 reports the first assessment of size at the onset of maturity for lobsters in the Limfjorden and a comparison of reproductive potential of female lobsters between several fishing grounds with a protected area to assess the impact of fishing. Both are important for the future management of the fishery by assessing the protection of egg production capacity provided by the current minimum landing size and the protection of berried females:

European lobsters were found to follow an annual reproductive cycle and size at first maturity when 50% of females become mature was 95.6 ±1.1 mm (95% CI) carapace length and thus 8.6 mm larger than minimum landings size. At minimum landing size only 26% of females were mature and in 2022 68% of landings were obtained from sizes smaller than size at first maturity. It must be noted that the ovigerous method used to assess female maturity, although the most used and recommended by ICES, leads to overly conservative estimates of size at first maturity, but by how much we cannot ascertain.

Reproductive potential in the Limfjorden was 74–86% lower in fished areas than in a small, protected area, albeit still exposed to low fishing mortality, due to both lower abundance and smaller size of lobsters. Egg production in the Limfjorden lobster population relies mainly on small lobsters, with 32–41% coming from sizes shorter than MLS in fished areas relative to 9% in the protected area. 50% of egg production in the Limfjorden originates from lobsters smaller than 91–96 mm similar to the mean length of landed females (Chapter 3), and only 4–9 mm larger than minimum landing size. This study, however, could not ascertain if current egg production levels in the Limfjorden are sufficient or insufficient to sustain recruitment and renewal of the lobster population.

Chapter 6 reports habitat utilisation and distribution of the European lobster in the Limfjorden:

A stratified-random field sampling campaign was used to inform models of abundance in relation to two key physical environmental conditions; namely depth and substrate type. Depth has a positive effect on lobster abundance, even in the limited depth ranges of the shallow Limfjorden. Furthermore, stoney habitats were the best habitat relative to sand, mud and mixed substrates.

The best habitat association model that could be fit to the snapshot data described these data well but could not reliably predict lobster abundance under novel conditions when tested in random-repeated cross validation. Therefore, no spatial interpolative predictions could be made to produce maps of potential habitat.

Chapter 7 reports an assessment of movement behaviour and home range size of lobsters in the Limfjorden from two approaches: a larger scale mark and recapture study in most of the western and central Limfjorden and a small-scale acoustic telemetry study at the Livø stone reef and marine protected area:

Lobsters generally moved short distances (few 100’s to 1,000 m) between mark and recapture locations, often in only a few weeks, showing strong site fidelity. However, larger scale movement was also observed one to two years after marking between fishing grounds and basins in the estuary of at least 4 and 12 km linearly. An acoustic telemetry study from end of August to early January, showed strong site fidelity with lobster home range (95% utilization distribution) similar to other locations in Europe, ranging from 100’s m^2 to few 10,000’s m^2. Daily movement was generally a few 100’s m, occasionally more than 500 m and up to ca. 2,000 m, with males travelling longer distances per day than females. Lobster activity was generally higher during night-time, but with significant individual variability. Distance travelled decreased in late autumn-winter, when temperatures decreased below 10°C.

Chapter 8 reports the assessment of fishing efficiency of the most common types of fishing gear used to catch lobsters in the Limfjorden:

Eel fyke nets were chosen as the baseline, as this gear can be used by both larger and smaller boats and is well known to all commercial and recreational fishermen in the area. Rigging with three eel fyke nets per string suited the vessels participating in the exploratory fishery. The number of lobster pots, nets and multi-pots that are needed to match the catch of lobster in three eel fyke nets were determined. Catch efficiency was significantly higher in the strings with four multi-pots than in strings with three eel fyke nets. None of the other tools were significantly different from the efficiency of eel fyke nets, but regardless, we use the mean values to calibrate the catch efficiency in different fishing gear.

Thus, we estimate catches of legal lobsters (i.e. larger than minimum landing size of 87 mm carapace length and excluding ovigerous females) in 2.1 (1.38–3.45) multi-pots correspond to the catch in three eel fyke nets. As a stand-alone tool, lobster pots are the least effective. Here it takes 9.7 (6.29–16.64) lobster pots to achieve the same number of legal lobsters as in three eel fyke nets. Gillnet and trammel nets are about equally effective when it comes to catching legal lobsters and for these gears it takes 2.3 (1.50–3.51) and 2.3 (1.24–6.52) nets respectively to catch a number of legal lobsters that correspond to the catch in three eel fyke nets.

In the period from 13/5 2021 to 25/6 2021, we conducted a total of seven full fishing days with a total catch of 1887 lobsters of which 368 individuals corresponding to approximately 150 kg were above the minimum size of 87 mm. In other words, on average 80% of the lobsters caught were below the minimum size. The high proportion of undersized lobster in catches was surprising and highlights the importance of increasing size selection in fisheries. The tools used in the experiment follow current legislation. Therefore, there are currently no devices to improve the size selection of lobsters and thus reduce the proportion of lobsters below the minimum landing size in the catch.

In e.g. Norway and Sweden, lobster is only caught in pots with mandatory use of escape vents. The vents ensure that the majority of lobster below minimum landing size escape. In June 2022, we conducted a sea trial testing the efficiency of such escape vents in the multi-pots. In spite of the flexible sides of the multi-pots, we demonstrated that the vents are efficient in releasing undersized lobster.

Chapter 9 reports recommendations for regulatory options that can be included in future management of the lobster fishery in the Limfjorden:

The recommendations are solely DTU Aqua's recommendations but have been made through discussions in the advisory group and in discussions with interested parties at open meetings at the start and end of the project. The recommendations fall into three categories and are in addition to the existing regulations in the area: General fisheries management, regulation of gear and other types of management tools. The general recommendations include: a) only whole lobsters should be allowed to be landed, b) rules should be harmonized inside and outside the Limfjorden, c) gear should not be deployed before the fishing season starts and d) a ceiling on landings in recreational fishing. Recommendations on gear include: (e) a ban on the use of nets in lobster fishing; (f) multi-pots (“kinaruser”) shall be defined as independent fixed-sized gear and (g) escape vents in multi-pots, traps and pots shall be mandatory. In addition, it is proposed to launch data collection programs to ensure better knowledge for managing the stock and to consider the possibility of using closed areas.

1. Project background and aims

The clawed European lobster, *Homarus gammarus*, occurs on the continental shelf of the north-eastern Atlantic from Morocco and the Mediterranean to the colder waters in Norway, commonly occurring in shelter providing habitats, such as rocky substrates but also soft sediments, of open coast and bays usually between 20 to 60 m deep, but reaching down to 150 m (e.g. Whale et al., 2013 and references therein for a review of *Homarus* biology).

Generally, large benthic decapods such as *Homarus* lobsters are seen as important in structuring benthic communities, through predator–prey interactions, and competition for food and habitat (e.g. Boudreau and Worm, 2012 for a review). *Homarus* lobsters are generalist and omnivorous feeders, mainly on crustaceans and molluscs, even their own species, and suffer predation mainly from fish and other crustaceans (e.g. shore crab), namely their own species (e.g. Whale et al., 2013; Boudreau and Worm, 2012). Changes in predation pressure may impact significantly their abundance, as described for the American lobster (e.g. Boudreau and Worm, 2010).

European lobster populations support valuable fisheries across its distribution with total landings of 4,000 to 5,000 tons from 2010 to 2020 (FAO, 2023). Landings decreased from the 1950's and 1960's, similarly to its close relative the American lobster, *Homarus americanus* (e.g. Wahle et al., 2020), namely in the UK, Norway, Sweden and Denmark (FAO, 2023). Landings in some European lobster fisheries have increased in the last two decades, e.g. UK, Netherlands and France (FAO, 2023). Danish European lobster landings have increased since early 2000's, mainly in the Limfjorden (Figure 1.1) from virtually no landings to ca. 24 tons per year, and more recently on the east coast of Jutland (ICES SD 22), (Fiskeristyrelsen, 2023a).

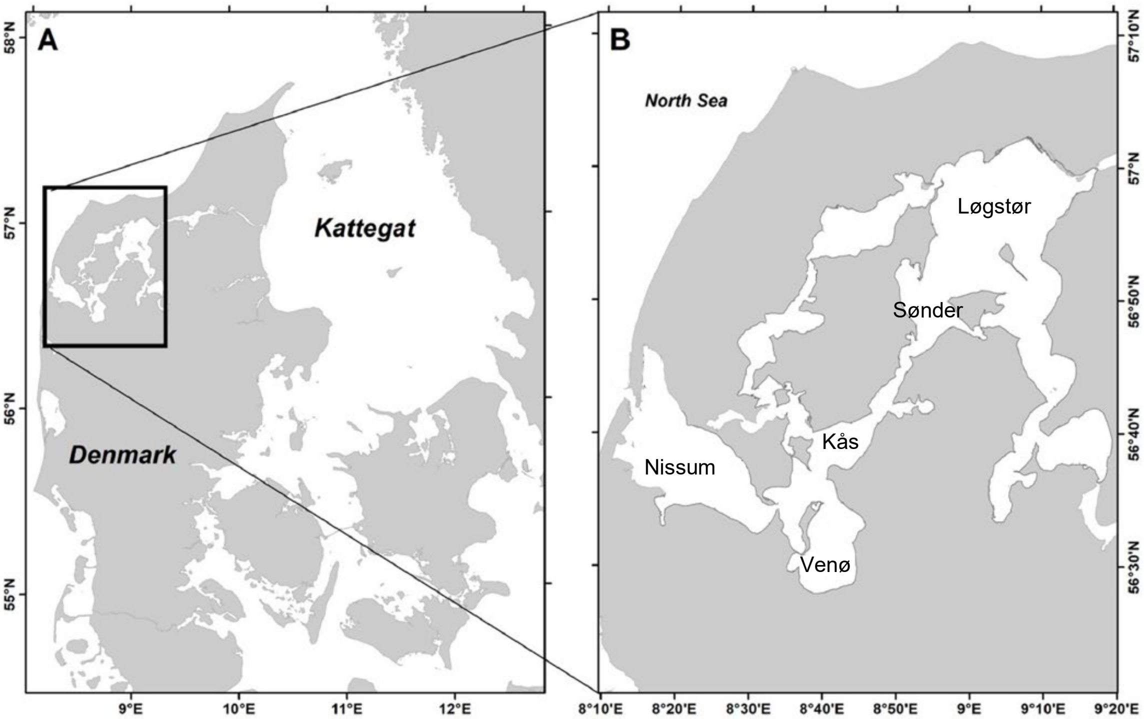

Figure 1.1. Map of Denmark (A) and the western part of Limfjorden (B) with selected broads.

The recent increase in European lobster landings in the Limfjorden likely reflect multiple effects, such as changes in predator-prey interactions or non-consumptive interactions taking place simultaneously with anthropogenic changes (e.g. Boudreau and Worm, 2012): reduction of predation pressure from a reduction in fish abundance (Tomczak et al., 2013); improvement of water quality; increase in food availability; and from warming and northward expansion of favourable egg and larvae development, growth and settlement conditions, similar to the American lobster (e.g. Philips et al., 2018 for a review).

The Limfjorden (Figure 1.1) is a relatively large (ca. 15,000 km^2), very shallow (mean of 4.8 m), microtidal, enclosed system dominated by muddy and sandy habitats, with large boulders or reefs almost absent, with significant salinity gradients (Hofmeister et al., 2009). The Limfjorden thus constitutes a peculiar habitat for European lobsters, contrasting with deeper and open bays and coastal habitats, which impacts population connectivity and renewal (e.g. larvae retention and migration), but may alter the impacts of environmental conditions (e.g. anoxia, low salinity, high summer temperatures or freezing in winter).

The lobster fishery in the Limfjorden is the main Danish lobster fishery with ca. 23.5 tons/year (2010-2022) and 63% of all Danish lobster landings since 2010 (Fiskeristyrelsen, 2023a), including from offshore fisheries (e.g. North Sea). The current fishery is now economically and culturally important targeting a high value species.

The Limfjorden lobster fishery is a complex mixed fishery, with significant commercial and recreational fishing, several types of gear allowed, no or little access or gear limitations and no catch limits. The fishery is regulated by a minimum landing size of 87 mm carapace length, prohibition of landing berried females and a closed period in July and August (Fiskeristyrelsen, 2023b).

The Limfjorden lobster fishery is a data poor fishery (ICES category 5, ICES, 2021), for which available data is limited to official landings and number of active fishing vessels (i.e. with registered landings) in the commercial part of the fishery, and no other information is available, namely on fishing effort, but also local lobster biology (maturity, size, growth, settlement, recruitment and environmental processes affecting it). Anecdotal reports by stakeholders indicate a high level of IUU fishing (irregular, unreported and unregulated) in the fishery. Therefore, the lack of knowledge on the fishery and lobster biology in the Limfjorden poses a significant risk that the resource is not being sustainably fished and managed. Given the slow growth and late maturity of European lobsters, recovery from unsustainable fishing or an overfished status is expected to take several years.

The overall aim of the project was thus to obtain data to develop information and advice for a sustainable management and regulation of the fishery. The project was structured in four work packages focused on:

1. An assessment of fishing pressure on the recreational and commercial fisheries (Work package 1; Chapter 2).
2. Development of a potential abundance index; assessment of the size structure of the lobster population and juvenile growth, maturity, lobster distribution relative to habitat, and lobster movement and behaviour in the Limfjorden (Work package 2; Chapters 3, 4, 5, 6 and 7).
3. An assessment of fishing gear selectivity and efficiency (Work package 3; Chapter 8).
4. Development of regulatory recommendations for the future management of the fishery (Work package 4; Chapter 9).

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2. Hummerfiskeri i Limfjorden

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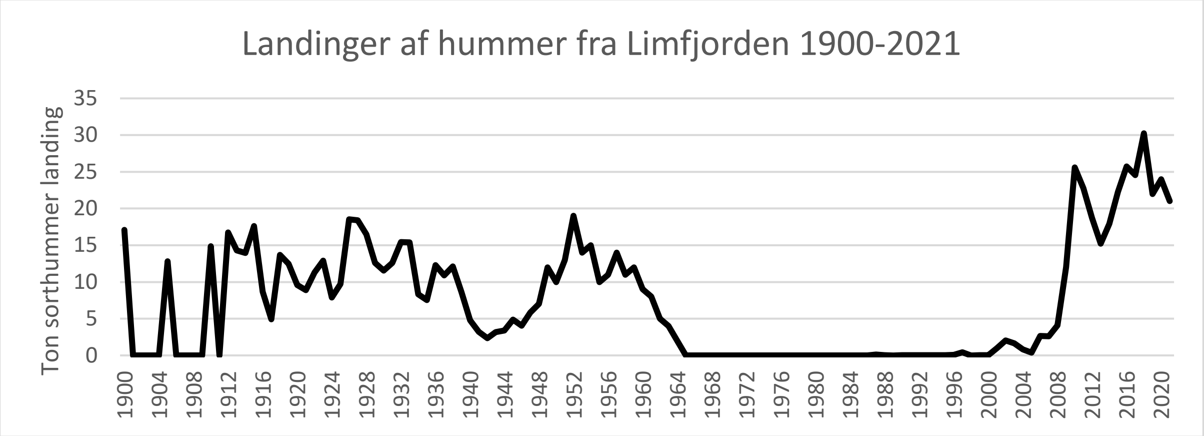
2.1 Generelt

Hummer fiskes med garn, ruser, tejner eller af snorkeldykkere med eller uden lydskræmmende midler. En Limfjordshummer er fangstmoden når den er 6-7 år gammel. Rygskjolden skal måle mindst 87 mm. Hummerfiskeri i Limfjorden er fredet i perioden 1 juli til 31 august og hummer med rogn er fredet hele året (BEK nr. 1144 af 01/12/2008 Gældende; https://fiskeristyrelsen.dk/media/10022/hummer-i-limfjorden.pdf). Figur 2.1 viser rapporterede landinger af hummer fra Limfjorden. Bestanden var rimelig stor i starten af 1900-tallet med årlige fangster omkring 15-20 tons. Bestanden blev næste total udryddet i fjorden i midten af 1960'erne af en kombination af overfiskeri og udledning af parathion-holdig spildevand fra Cheminova (Hoffmann, 2005). I 1980'erne begyndte hummer igen at optræde lejlighedsvis i forsøgsfiskeriet i Nissum Bredning og har siden spredt sig igen i Limfjorden. Fiskeriet er på det tidligere niveau, hvis ikke højere.

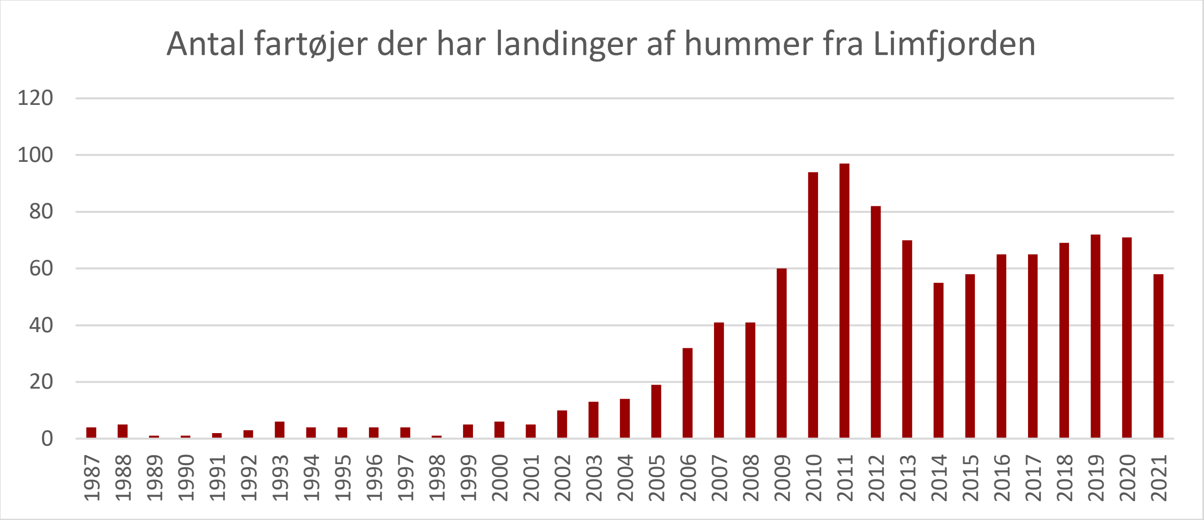


Figur 2.1. Overblik over landinger rapporteret fra Limfjorden i perioden 1900-2021. Datakilden er afregninger for perioden 1978-2019. For perioden 1900-1977 kommer data fra indtastede fiskerårbøger.

2.2 Kommercielle fiskeridata

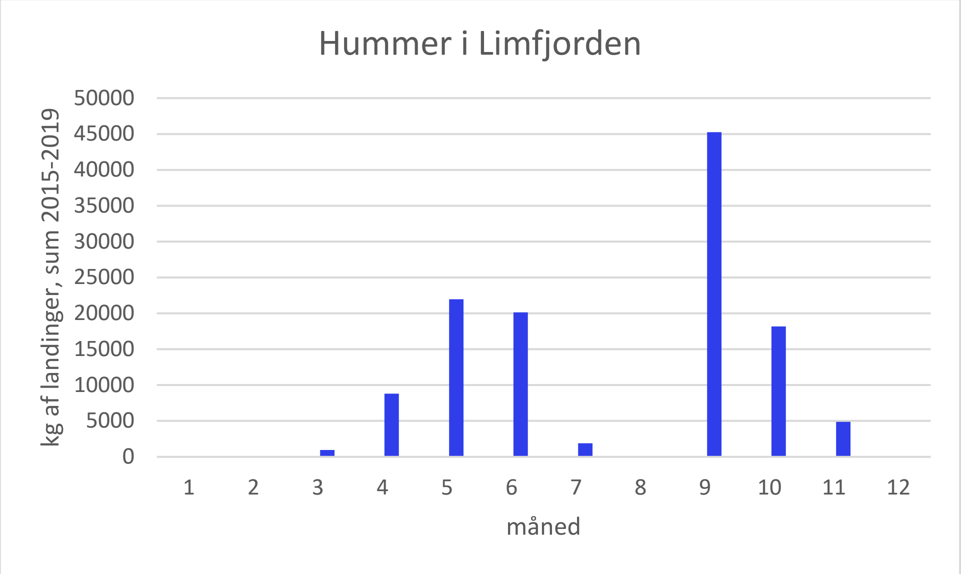
Landinger i Limfjorden

Data om antal fartøjer, der har landinger af hummer fra Limfjorden (Figur 2.2) viser, at antal fartøjer toppede i årene 2010-2011 og ligger fortsat på et høje niveau end før 2000.



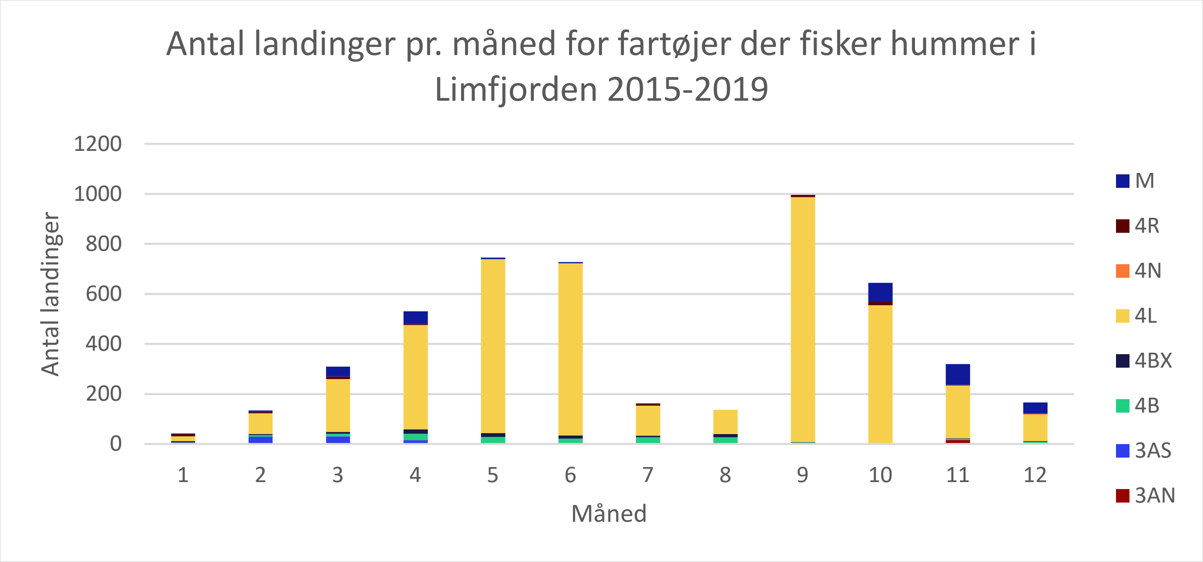
Figur 2.2. Overblik over antal fartøjer, der landede hummer fra Limfjorden i perioden 1987-2021. Datakilden er afregninger for perioden 1978-2019. For perioden 1900-1977 kommer data fra indtastede fiskerårbøger.

Landinger af hummer topper i september måned, lige efter lukkerperioden (juli-august) slutter og falder i løbet af vintermånederne, mens fiskeriet øges i april (Figur 2.3). Selve efforten (indsats) for skibe der lander hummer ses i Figur 2.4, hvor størst antal landinger forgår i september. Efforten afspejler til dels hummer-landingerne, dog stiger det antal hummer der landes per landing væsentligt i september i forhold til eksempelvis maj-juni og oktober. For eksempel, set i forhold til gennemsnit for juni måned, stiger antal landinger i september med 142%, mens hummer landingerne i kg stiger med 224% i samme måned.

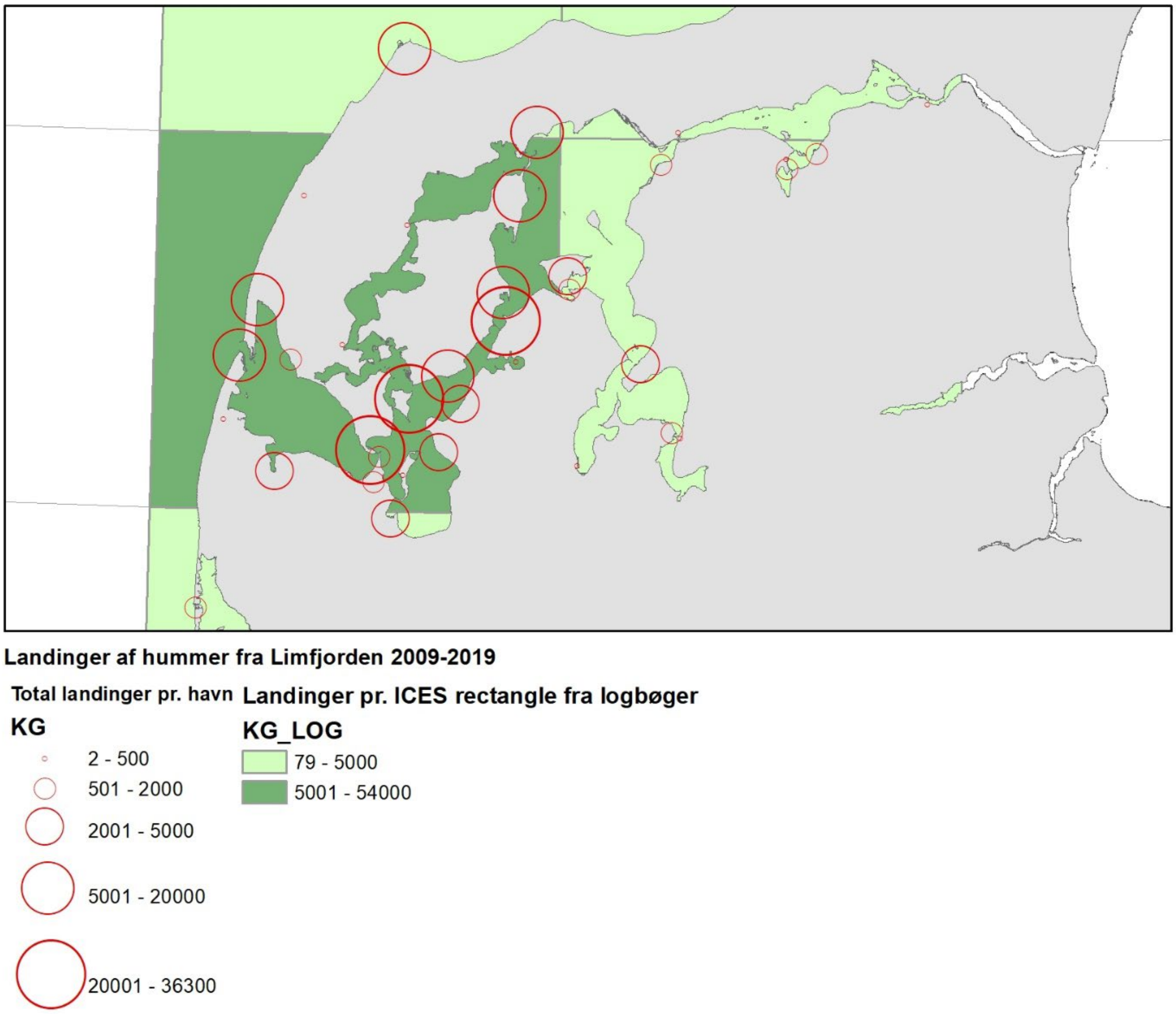


Figur 2.3. Fordeling af landinger (total sum i kg) af hummer i Limfjorden over året. Tallene er gennemsnit for 5 år i perioden 2015-2019.

Hummer i det kommercielt fiskeri fanges primært i den vestlige del af Limfjorden (Figur 2.5).



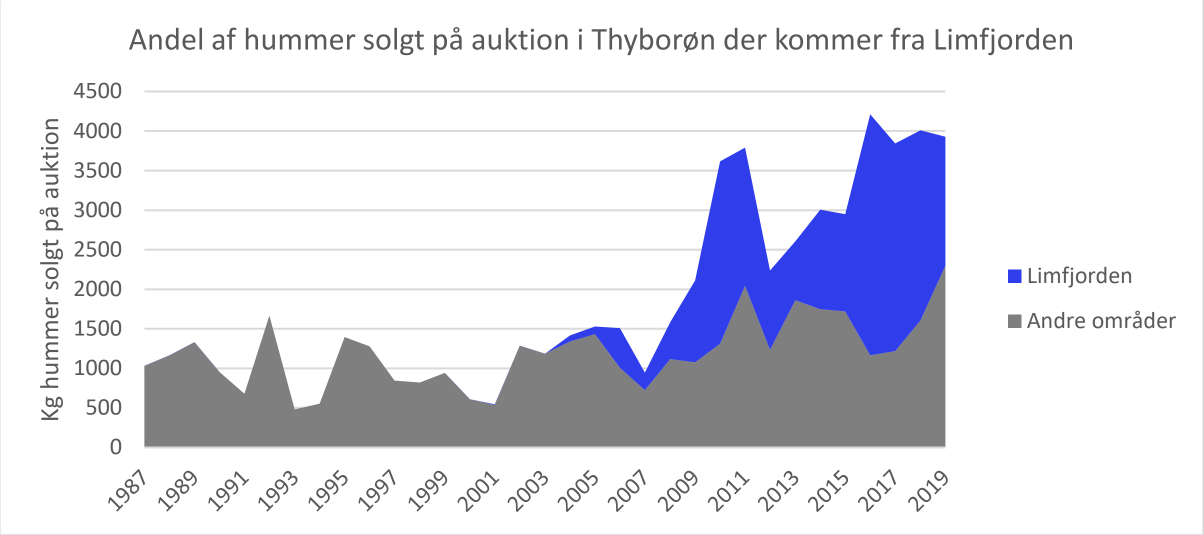
Figur 2.4. Fordeling over året af antal landinger for fartøj der fisker hummer i Limfjorden. Tallene er gennemsnit for 5 år i perioden 2015-2019. 4L dækker landinger i Limfjorden. De andre er landinger i andre områder eller i muslingeområder i Limfjorden.



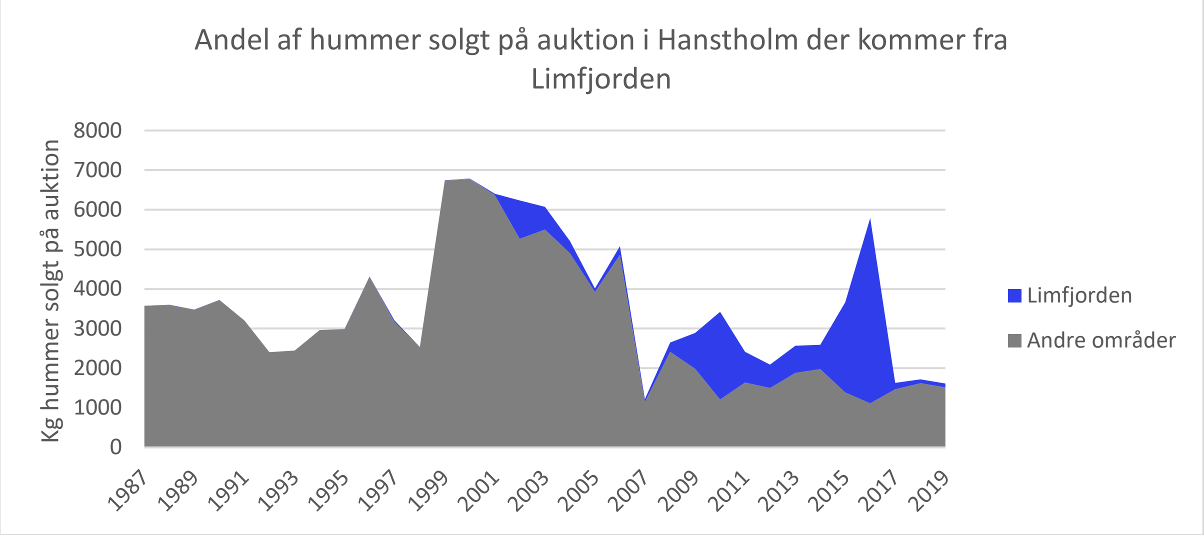
Figur 2.5. Kort over landinger af hummer fra Limfjorden 2009-2019. De røde cirkler viser total landinger pr. landingshavn fra afregningsdata, i baggrunden vises landinger pr. ICES rektangel fra fartøjer med logbøger.

Kommercielle landinger udenfor Limfjorden

Hummer fra Limfjorden landes også i de havne fx Thyborøn og Hanstholm som ligger uden for Limfjorden. Landinger i Thyborøn fra 'andre områder' har været nogenlunde stabil, men landinger fra Limfjorden begyndte efter 2000 og siden 2009 har de bidraget til en 2-3 dobling af hummerlandingerne i Thyborøn (Figur 2.6). Landinger af hummer i Hanstholm var højest i perioden 1999-2006 og var primært fra 'andre områder' helt frem til 2007 (Figur 2.7). Efter 2007 faldt hummerlandingerne fra 'andre områder, men andelen af hummerlandinger fra Limfjorden steg og toppede i 2016.

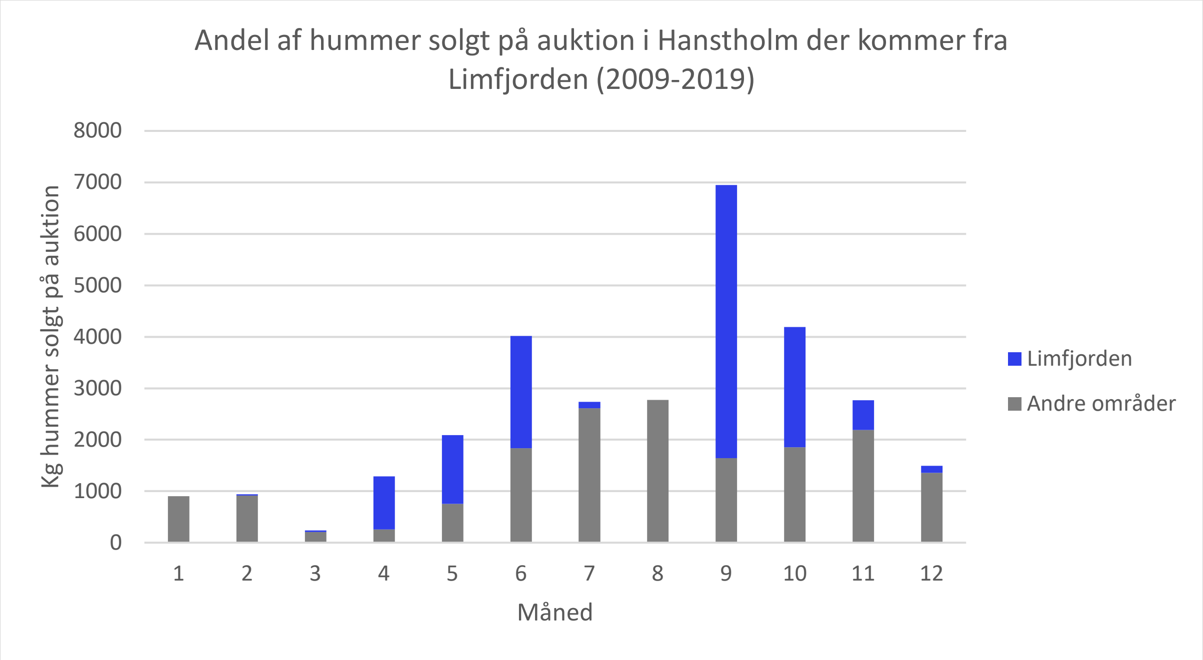


Figur 2.6. Hummer solgt på auktion i Thyborøn pr. år for perioden 1987-2019 opdelt i landing fra Limfjorden og andre områder.

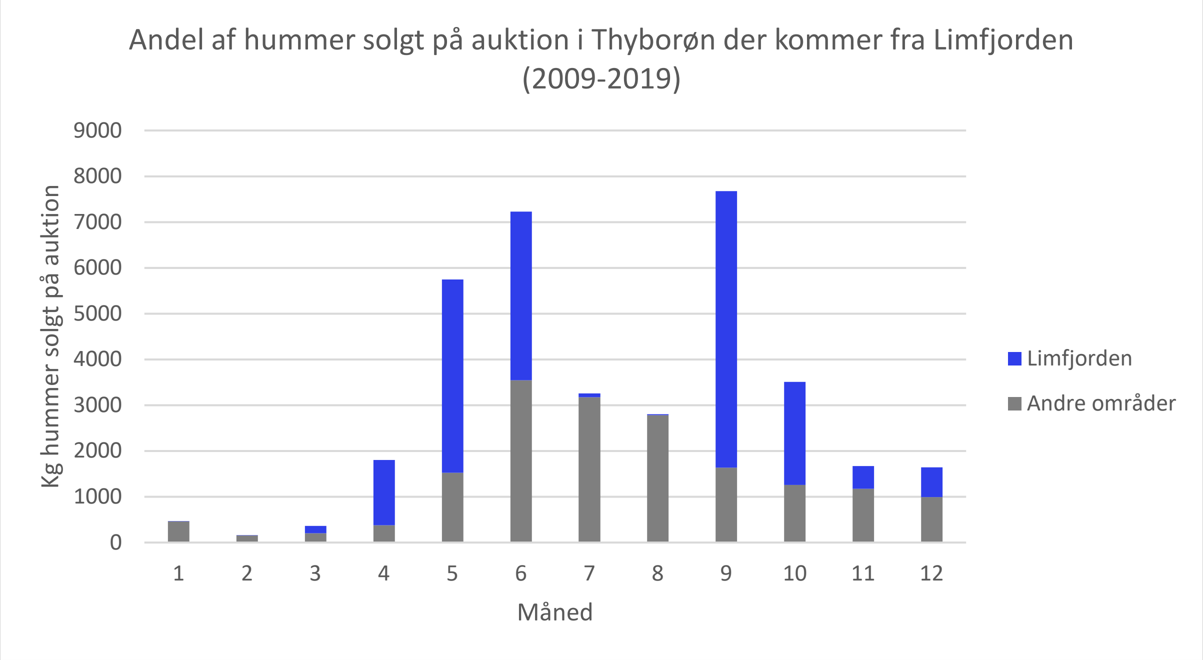


Figur 2.7. Hummer solgt på auktion i Hanstholm pr. år for perioden 1987-2019 opdelt i landing fra Limfjorden og andre områder.

I både Thyborøn og Hanstholm sælges hummer på auktion året rundt, men med det højeste antal i september, lige efter sommerlukningsperioden i Limfjorden (Figur 2.8 og 2.9).



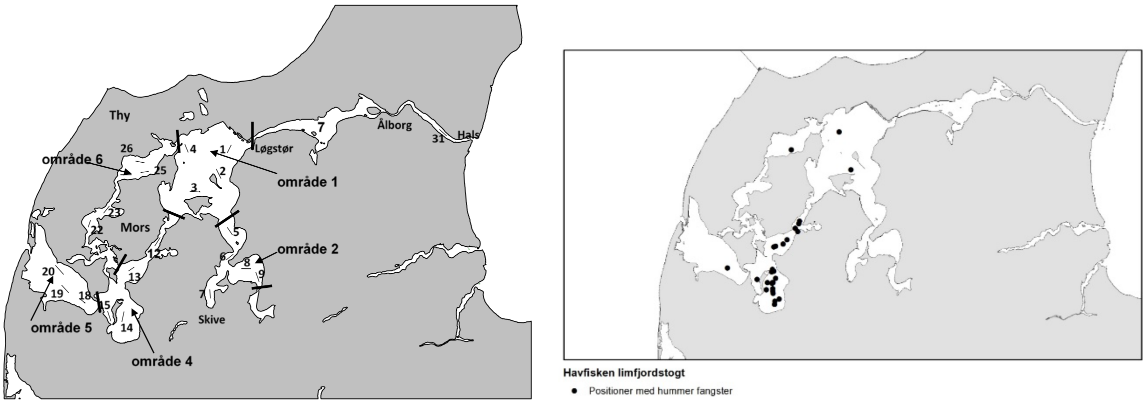
Figur 2.8. Hummer solgt på auktion i Hanstholm pr. måned summeret for perioden 2009-2019 opdelt i landing fra Limfjorden og andre områder.



Figur 2.9. Hummer solgt på auktion i Thyborøn pr. måned summeret for perioden 2009-2019 opdelt i landing fra Limfjorden og andre områder.

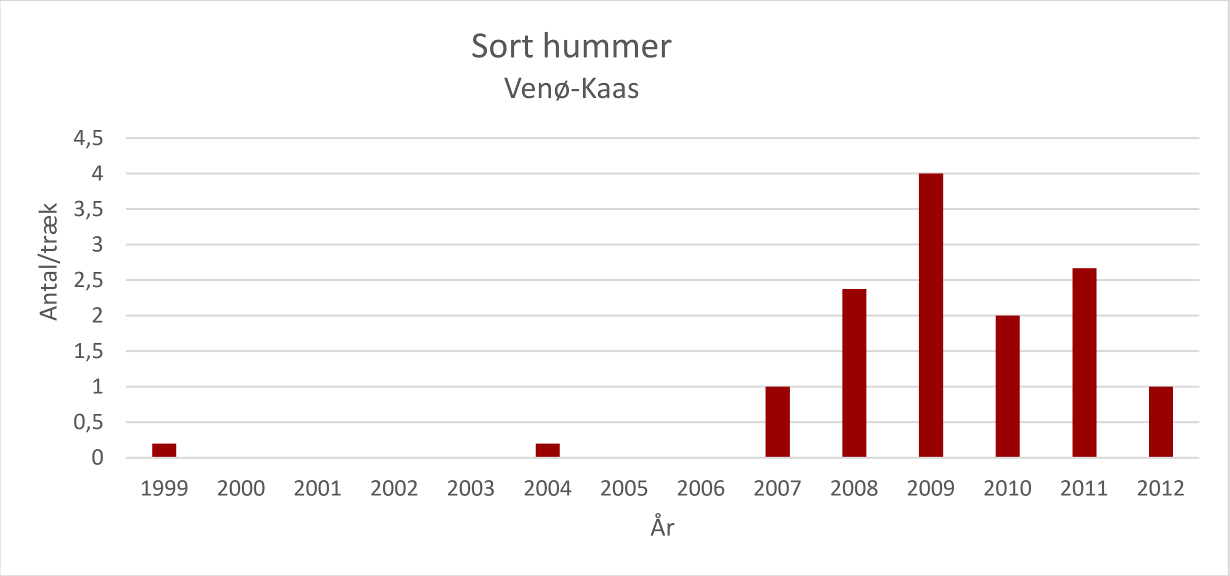
2.3 Forsøgsfiskeri-data

De årlige forsøgsfiskeritogter i Limfjorden gennemført siden 1984 (Hoffmann 2005) har vist samme mønster som landingerne i det kommercielle fiskeri. Før 2000 blev der sjældent fanget hummer, og de sparsomme fangster var ofte større (og ældre) individer (E. Hoffmann, pers. komm.). Efter 2000, blev der fanget en del hummer i Salling Sund, Kaas Bredning og rundt om Venø (område 4 i Figur 2.10). Enkelte eksemplarer blev fanget i Nissum (område 5), Thisted (område 6) og Løgstør Bredning (område 1) (Figur 2.10). Fiskeriet foregik med TV3 trawl på den tidligere skib Havfisken. Der blev slæbt på blødbund i 30 min med en slæbefart på 2,5 – 2,7 knob (Hoffmann, 2005).



Figur 2.10a+b. Kort over Limfjorden (tv), med område inddelinger (tykke sorte streger) og trawlstreger (små sorte streger med nummer) gennemført i forsøgsfiskeriet, samt positioner hvor der blev fanget hummer i Limfjorden (th).

Efter 2000 begyndte hummer at optræde i fangsterne primært i område 4 (Figur 2.10) og især i årene 2007-2011 (Figur 2.11). Forsøgsfiskeriet blev ikke gennemført efter 2012.

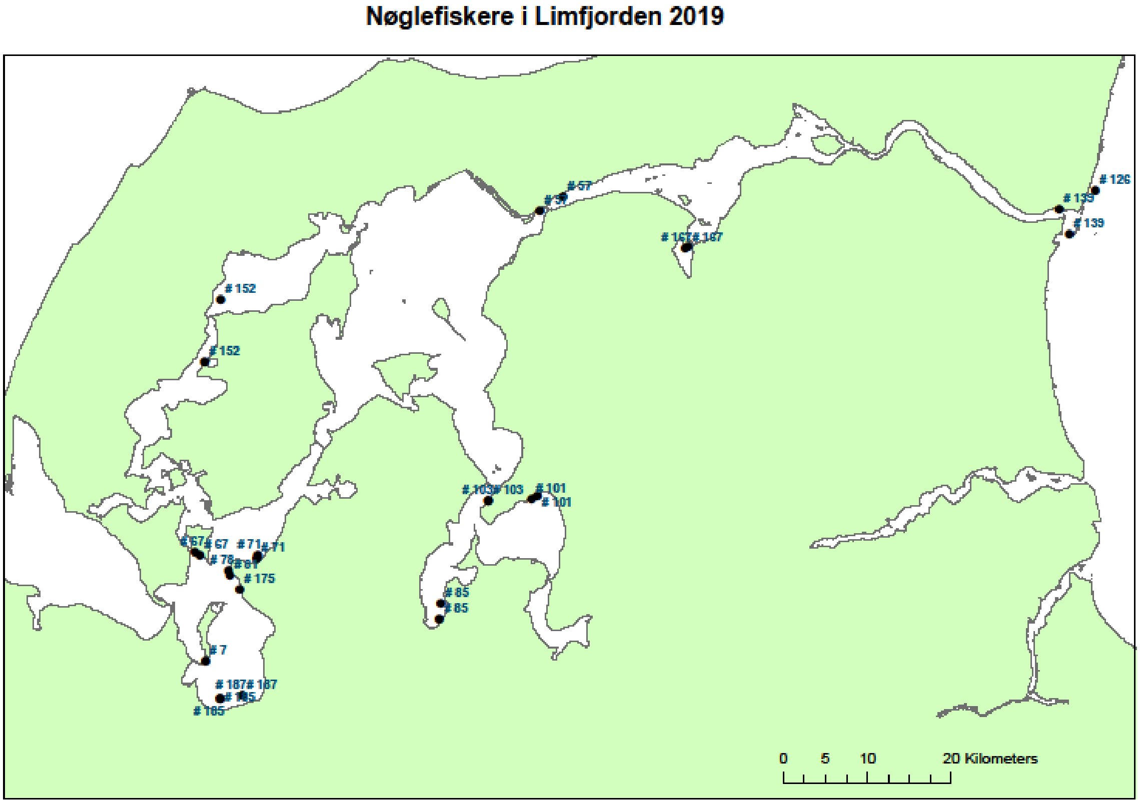


Figur 2.11. Fangster af hummer per 30 min træk med TV3 trawl i område 4 (se Figur 2.10) i Limfjorden.

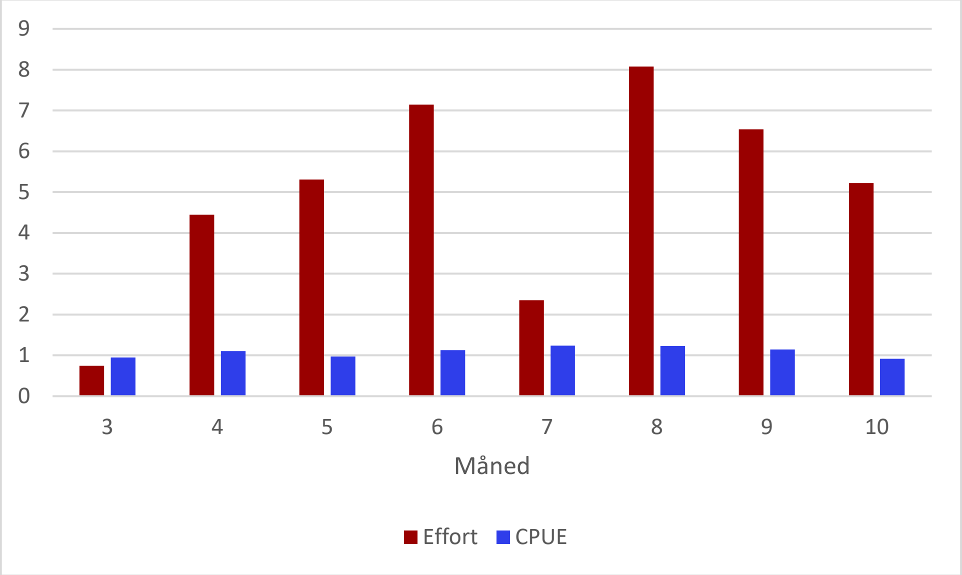
2.4 Fritidsfiskeri – nøglefiskerdata

Omfanget af det rekreative fiskeri efter hummer kendes ikke. Igennem nøglefiskerprojektet er der information om fangstraten fordelt på år og måned (CPUE) med både garn og ruser. Fordelingen af nøglefiskere i Limfjorden i 2019 er vist i Figur 2.12.

Hummer fanges primært i området omkring Venø og Kås Breding også af fritidsfiskerne. I den østlige del af Limfjorden i Nibe Bredning og ved Hals bliver der ikke fanget hummer. Ved Løgstør er der kun blevet fanget 1 stk i ruser i 2009. I Thisted bredning er der totalt fanget henholdsvis 2, 31 og 18 hummer i 2016, 2018 og 2019. I Lovns bredning og Skive Fjord er der ikke fanget hummer, men der er blevet fanget 1 stk i august 2013 ved Hvalpsund.



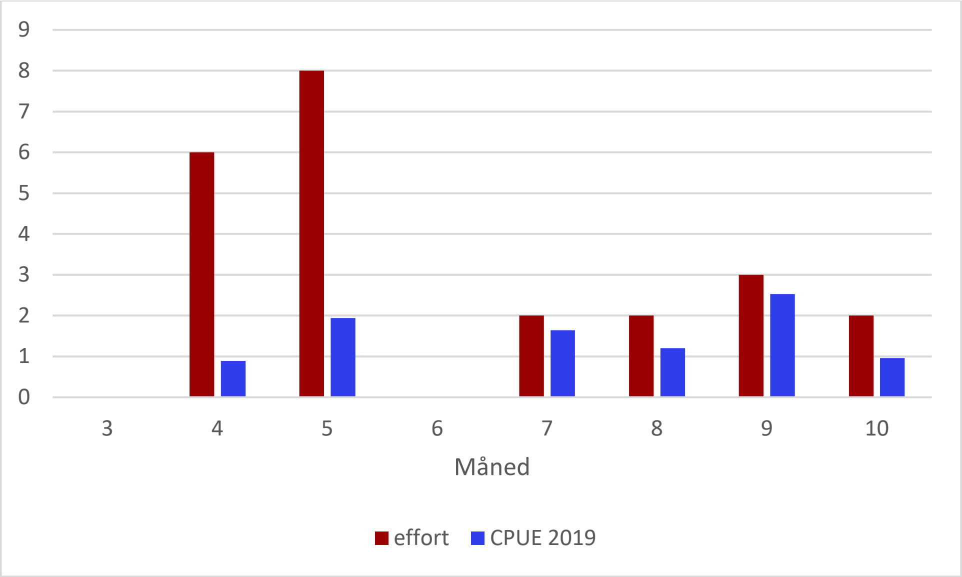
Figur 2.12. Kort over Limfjorden med placering af de nøglefiskere i fjorden. Når nummeret optræder to gange, er det fordi der fiskes med både garn og ruse.



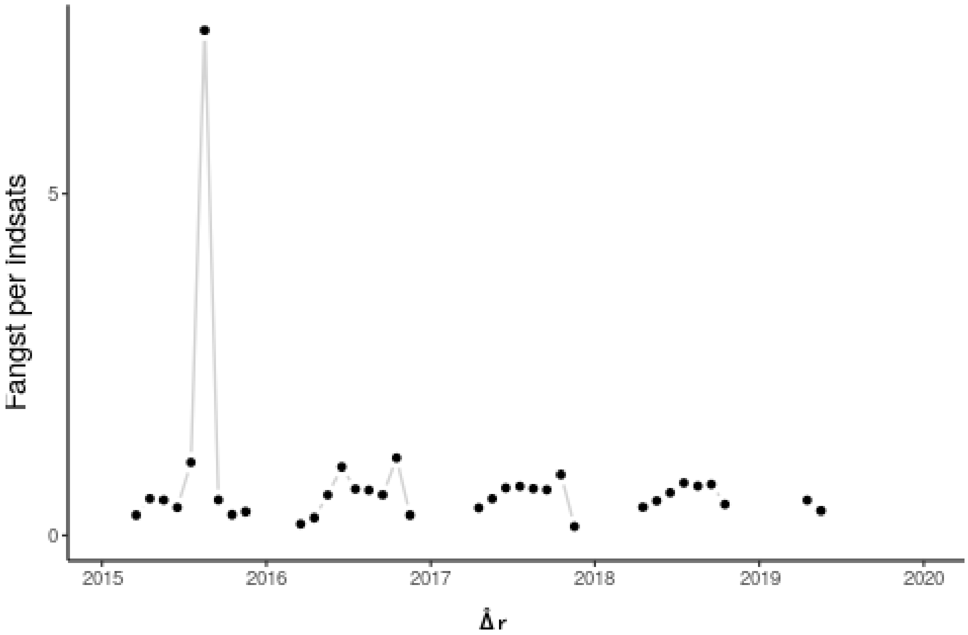
Figur 2.13. Den gennemsnitlig månedlige effort (antal ture) og fangst af hummer (antal) per tre ruser over 24 timer, fordelt over året for årene 2005-2019.

I området omkring Venø og syd for Venø har der været fisket med ruse siden 2005. Den gennemsnitlige fangst hver gang der blev sat tre ruser ude i 24 timer lå mellem 0,9 og 1,2 og højest i juli og august måned. Den gennemsnitlig effort (hvor mange gange der blev fisket) var lavest i juli måned og højest i august måned (Figur 2.13). Fiskeriet med ruser foregik mellem marts og oktober.

I området omkring Venø og syd for Venø, blev der kun fisket med garn af én nøglefisker og kun tre gange i september 2018. Den gennemsnitlige fangst var 1,7 hummer per tre garn over 12 timer. I 2019 blev der fisket af to nøglefiskere med garn og over flere måneder (Figur 2.14). Størst effort var i foråret, mens efforten lå på 2-3 gange per måned resten af året. Der blev ikke fisket i juni måned. Fangsten af hummer varierede mellem 0,9 og 2,5 per tre garn over 12 timer.

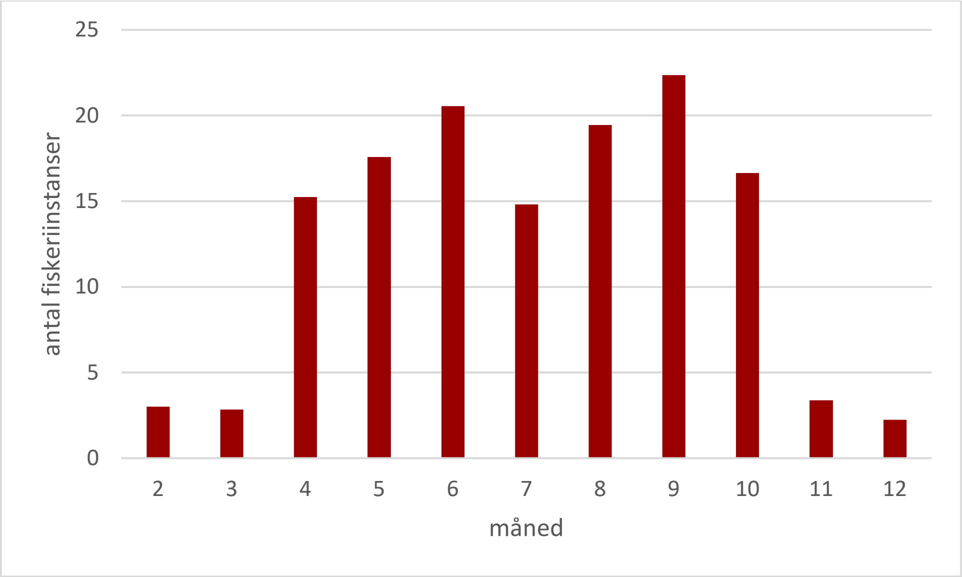


Figur 2.14. Den gennemsnitlig månedlige effort (antal ture) og fangst af hummer (antal) per tre garn over 12 timer, fordelt over året i 2019 omkring Venø.



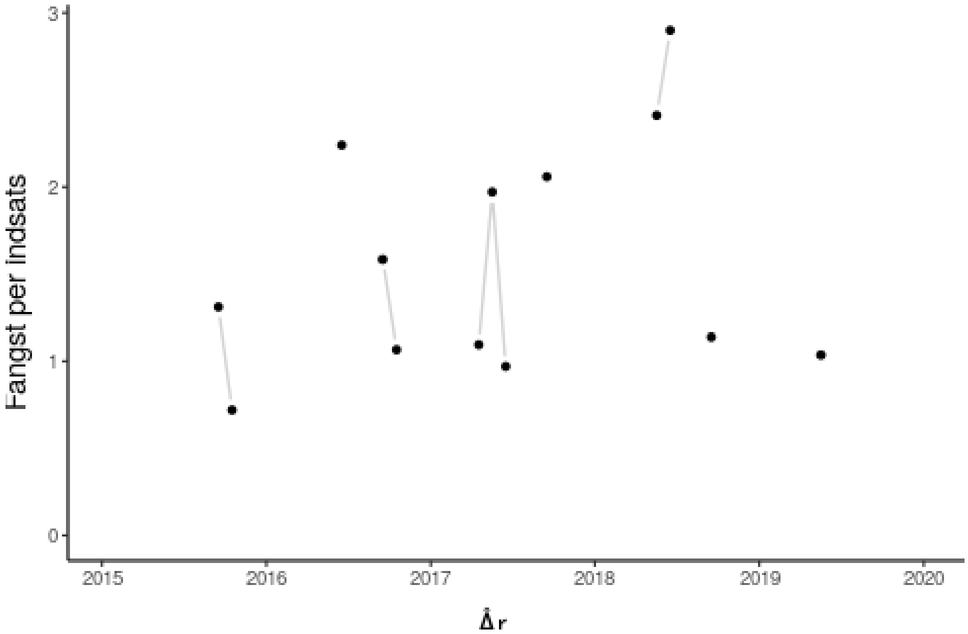
Figur 2.15. CPUE (fangst hver gang der fiskes med ruser over 24 timer) af hummer per måned over de sidste 5 år i Kås Bredning.

I Kås Bredning fanges der generelt et par hummer hver gang der fiskes med ruser (Figur 2.15) og ser ud til at være konstant de sidste 5 år. Efforten, dvs. det antal gange der fiskes, varierer over året og er mest intenst fra april til og med oktober (Figur 2.16).



Figur 2.16. Gennemsnitlige antal gange, der fiskes med ruser i Kås Bredning fordelt over året for årene 2008-2019 .

Fiskeri med garn foregår med færre instanser end med ruser i Kås Bredning og variere fra 1 til 4 gange over året i alle årene 2008-2019 (data ikke vist i figur pga. for få data). Fangst af hummer hver gang der fiskes med garn i 12 timer, er vist i Figur 2.17 og er generelt omkring en hummer og højst tre hummer per 12 times garnfiskeri.



Figur 2.17. CPUE (fangst hver gang der fiskes med garn over 12 timer) af hummer per måned over de sidste 5 år i Kås Bredning.

2.5 Spørgeskemaundersøgelsen udført af Danmarks Statistik

Denne web-baseret spørgeskemaundersøgelse blev gennemført i samarbejde med et andet projekt. Formålet var at få et indblik i fritidsfiskeriet efter hummer. Der var derfor interesse i at få indblik i hvor mange ture efter hummer den enkelte fritidsfisker fortog, hvor mange hummere der blev fanget på hver tur, og hvilke redskaber der blev anvendt for at fange hummer.

Et antal tilfældig udvalgte personer fik spørgeskemaet hver halve år fire gange, og blev spurgt om fiskeriet i de to foregående kvartaler. Svarene blev samlet og opgjort per halvår. Nogle af respondenterne kan være gengangere.

Respondenterne skulle angive om de havde fritidsfiskerkort eller lystfiskerkort.

Ud af det samlede antal spørgsmål er det kun fire af spørgsmålene, der relaterede sig til sorthummere og dermed var relevant for dette projekt:

1. Hvor mange ture har du haft efter sorthummer i (gælder for første eller andet halvår 2020 og 2021)?
2. I hvilket område har du fisket efter sorthummer (svar muligheder var: 1 Limfjorden; 2 Nordsøen; 3 Østersøen; 4 Kattegat; 5 Andet)?

Baseret på svar for spørgsmål 2, blev der yderligere spurgt følgende to spørgsmål:

3. Hvor mange sorthummer har du fanget (over en bestemt periode)?
4. Hvilke redskaber har du benyttet mest til at fange sorthummer?

Resultater

Kun data, der vedrører Limfjorden er oparbejdet i det følgende. Antal respondenter, der havde fritids- eller lystfiskertegn opgjort per halvår er angivet nedenfor i tabel 2.1:

Tabel 2.1. Opgørelse af respondenter med enten fritidsfiskertegn eller lystfiskertegn opgjort per halvår i 2020 og 2021.

	1-2020	2-2020	1-2021	2-2021
Antal med fritidsfiskertegn	1525	1629	1461	1527
Antal med lystfiskertegn	1786	1780	1564	1527

Der var næsten lige mange der fiskede med enten fritidsfiskertegn eller lystfiskertegn blandt respondenterne. Antal fritidsfiskere, der responderede om de fiskede som fritidsfisker opdelt i perioder på halve år er vist i tabel 2.2. Det var jævnt omkring halvdelen af respondenter med fritidsfisketegn, her havde foretaget fiskeri i hvert halvår.

Tabel 2.2. Antal respondenter med fritidsfiskertegn og hvor mange af dem, der har foretaget fiskeri opgjort per halvår i 2020 og 2021.

	1-2020	2-2020	1-2021	2-2021
Antal fritidsfiskere, der responderede	1525	1629	1461	1527
Antal fritidsfiskere, der fiskede i perioden	683	812	602	743

Ikke alle fritidsfiskere fiskede efter hummer. I tabel 2.3 er angivet hvor mange ture efter hummer fritidsfiskerne havde foretaget i de fire halvårsperioder.

Tabel 2.3. Antal fritidsfiskere, der havde én eller flere (op til 40) ture, i det pågældende halve år, total antal fiskere med én eller flere tur per år (2020-T og 2021-T) og total antal ture det pågældende år. 1-2020 og 1-2021 er første halvår i hhv. 2020 og 2021. 2-2020 og 2-2021 er andet halvår i hhv. 2020 og 2021.

Antal ture	1-2020	2-2020	2020-T	Total antal ture	1-2021	2-2021	2021-T	Total antal ture
1	4	1	5	5	6	6	12	12
2	4	6	10	20	3	12	15	30
3	3	7	10	30	1	11	12	36
4	2	5	7	28	3	2	5	20
5	6	4	10	50	3	5	8	40
6	1	6	7	42		4	4	24
7	2	2	4	28		1	1	7
8		2	2	16	4	1	5	40
10	7	6	13	130	2	9	11	110
11		1	1	11				0
12	2	1	3	36	1	1	2	24
13		1	1	13				0
15		3	3	45	2	3	5	75
16	1		1	16		2	2	32
20	1		1	20				
22		1	1	22				
30		1	1	30				
40		2	2	80				
Total				622				450

De fleste fiskede op til 10 ture per halvår og langt færre fiskede flere end 10 tur per halvår. I begge år, i den første halvdel af året havde 88% af respondenterne der fiskede efter hummer i Limfjorden svarede at de foretog mellem 1 og 10 ture. Enkelte, de resterende 12% gennemførte flere end 10 ture og en enkelt op til 20 ture. Generelt fiskede flere fiskere i anden halvdel af året. Her havde hhv. 80% og 89% kun fiskede mellem 1 og 10 ture, mens resten fiskede flere end 10 ture og enkelte op til 40 ture i 2020 og op til 16 ture i 2021.

Fiskeriefforten efter hummer i Limfjorden har derfor ifølge disse svar fra respondenterne været højere i anden halvår. For de enkelte fiskeres vedkommende har de fleste foretaget 10 eller færre ture per halvår.

Der blev kun svaret på antal sorthummer fanget af fritidsfiskere i Limfjorden i perioden første halvdel af 2020 (1-2020) Der blev svaret at der var fanget mellem en og 38 sorthummer i løbet af første halvdel af 2020.

Svarerne fra lystfiskerne for spørgsmålene vedrørende fangst af hummer i Limfjorden blev også opgjort. I tabel 2.4 er opgjort antal lystfiskere der gennemførte lystfiskeri i Limfjorden i løbet af 2020 og 2021.

Tabel 2.4. Antal lystfiskere, der havde én eller flere (op til 30) ture, i det pågældende halve år, total antal fiskere med en eller flere tur det år (2020-T og 2021-T) og total antal ture det pågældende år. 1-2020 og 1-2021 er første halvår i hhv. 2020 og 2021. 2-2020 og 2-2021 er andet halvår i hhv. 2020 og 2021.

Antal ture	1-2020	2-2020	2020-T	Total antal ture	1-2021	2-2021	2021-T	Total antal ture
1	1	2	3	3	1	5	6	6
2		2	2	4	1		1	2
3		2	2	6	2		2	6
4		1	1	4	1		1	4
5	1	1	2	10		1	1	5
6		1	1	6	1		1	6
30						1	1	30
Total antal ture				33				59

Antal sorthummer fanget af lystfiskere i Limfjorden er blevet indrapporteret for alle fire halvårsperioder (Tabel 2.5).

De fleste lystfiskere rapporterede at de foretog op til 6 ture (en enkelt 30 ture) over en 6 måneders periode. Der blev foretaget flest ture med størst total fangst af hummer i anden halvdel af 2020. Her ser det ud til at lystfiskerne var i stand til at fange et antal hummer over en 6-måneders periode med en forholdsvis lille indsats (antal ture).

Tabel 2.5. Antal ture efter hummer og antal fanget hummer i Limfjorden af lystfiskere.

1-2020		2-2020		1-2021		2-2021	
Antal ture	Antal hummere	Antal ture	Antal hummere	Antal ture	Antal hummere	Antal ture	Antal hummere
1	1	1	1	1	6	1	1
5	4	1	4	2	2	1	1
		2	4	3	1	1	4
		2	30	3	4	1	5
		3	3	4	6	1	9
		3	15	6	5	5	20
		4	2			30	400
		5	10				
		6	12				

Flere lystfiskere var i stand til at fange et antal hummer over en 6-måneders periode med en forholdsvis lille indsats (antal ture).

Opsummering

Antal fritidsfiskere, der fisker efter hummer i Limfjorden kendes ikke. Ud fra respondenternes svar, fisker flest fritidsfiskere i anden halvdelen af året og fangsten på en sæson (6 måneder) kan være på op til 38 hummer. Det ser ud til at være færre lystfiskere, der fisker efter hummer i fjorden og at indsatsen (antal ture) er også generelt lavere for lystfiskerne. Dog kan fiskeriet være effektiv som eksempelvis i anden halvdel af 2020.

3. Temperature corrected landings-per-unit effort in the commercial lobster fishery as a potential indicator of European lobster (*Homarus gammarus*) abundance in the Limfjorden

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3.1 Rationale

Fisheries management require the collection of data, either dependent or independent from the fishery, to support the assessment of fishing impacts but also stock (i.e. harvestable fraction) and population status and renewal. Overfishing can result in significant lower catches than under adequate fisheries management often resulting in detrimental ecosystem shifts (e.g. Pauly et al., 1998, Grainger 1999, Pitcher, 2001). If inadequately managed, most fisheries will go through, at least partially, a sequence of stages: undeveloped, developing, fully exploited, overfished, and collapsed or closed (Froese and Kesner-Reyes, 2002).

Indices of abundance are commonly used in fisheries management and stock assessment as indication of trends in relative abundance of a stock or population over time, i.e. changes in the index are proportional to changes in the abundance of the stock or population through the catchability coefficient (e.g. Arreguín-Sánchez, 1996; Maunder and Punt, 2004). Catch and landing data per se are of limited value, although trends may be significant, as they can fluctuate for several reasons that are unrelated to the abundance of the fished population, namely changes in fishing effort.

Therefore, catch or landing data are normalized for variations in fishing effort to catch or landing per unit effort (CPUE or LPUE). Effort is usually estimated from boat-fishing days, fishing events or amount and type of gear. However, and importantly, landing-based indices ignore the fraction of the catch that is discarded (e.g. juvenile or ovigerous specimens) and thus not landed, but is part of the population. However, CPUE or LPUE often must be standardized to account for impacts from factors other than changes in abundance that may cause changes in catch rates over time, such as changes in the efficiency of the fishing fleet or environmental factors that affect catchability (e.g. Maunder and Punt, 2004; Maunder et al., 2006).

The Limfjorden lobster fishery is a mixed fishery with significant commercial and recreational fishing, multiple types of gear allowed, only number of gear limitation in recreational fishing and no limitations or registration of commercial fishing effort. Currently, the Limfjorden lobster fishery is an ICES category 5 (ICES, 2021) data poor fishery for which available data is limited to the official landings and number of active fishing vessels (i.e. with registered landings) in the commercial part of the fishery. No information is thus available for the significant recreational fishery (Chapter 2, this report) but also on fishing effort in the commercial fishery, such as the number of fishing days/events, the number and type of gear used in the commercial fishery. Furthermore, both the commercial and recreational fishery have recently undergone changes in fishing gear used in the last 5-10 years, usually replacing lower efficiency fyke nets, gill nets and trammel nets, with higher efficiency multi-pots (Chapter 8, this report).

Historical lobster landings in the Limfjorden show that lobster fishing increased since mid-2000's after a period of 40 years with virtually no landings. Over the last 12 years, landings have fluctuated by over 100%, with the fishery appearing to be dependent on new recruits to support a significant fraction of landings, and the population showing signs of growth overfishing having a significantly truncated size distribution with low abundance of medium to large lobsters (Chapter 4, this report). Therefore, management of the fishery would greatly benefit from timeseries of indices of abundance or biological indicators (e.g. size, maturity or egg production related) other than just landing data from the commercial fishery.

The aim of this study was to develop an index of abundance for the Limfjorden lobster fishery based on landings-per-unit effort (LPUE), correcting for the known effect of temperature on lobster activity and thus catchability (e.g. McLeese and Wilder, 1958; Branford, 1979; Smith et al. 1999; Moland et al., 2011; Matić-Skoko et al., 2022), but also its effect on fishing effort as reflected in a seasonally changing number of active fishing boats per month. Once temperature effects are accounted for, residual LPUE variability should better reflect changes in the abundance of the lobster population.

3.2 Methods

Temperature data

Since no continuous water temperature data was available, monthly mean air temperature between 2010 to 2022 was obtained for Thisted (Figures 3.1 and 3.2), a central location in the Limfjorden (DMI, 2022: https://www.dmi.dk/vejrarkiv/). Air temperature was assumed to function as a proxy for water temperature in the region, capturing its seasonal changes.

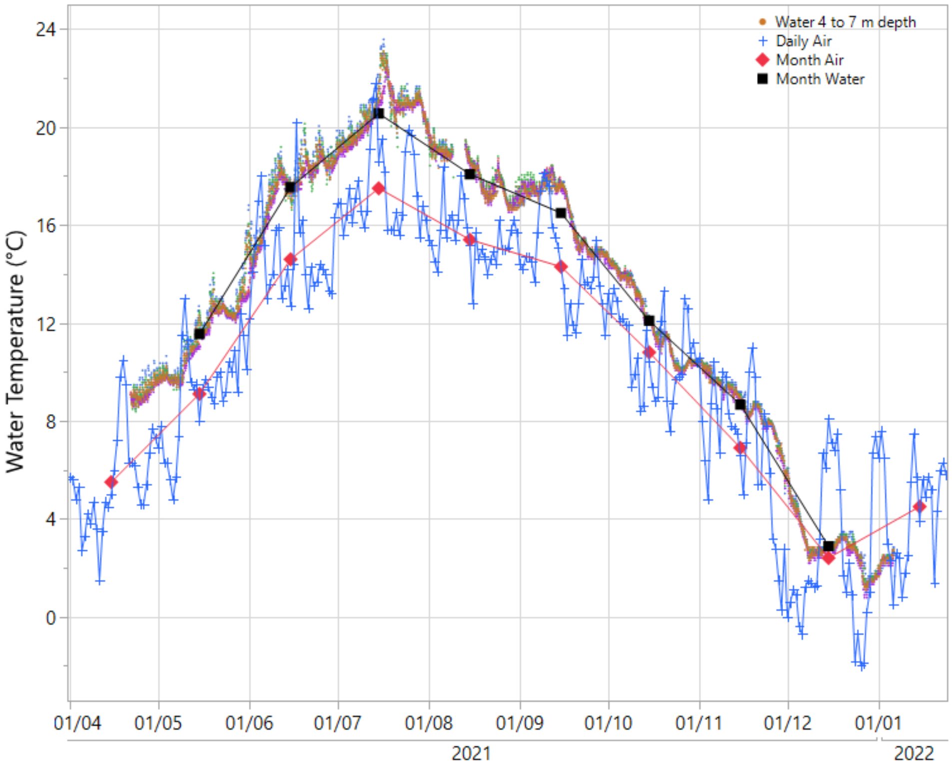

Figure 3.1. Air and water temperature in the central Limfjorden from April 2021 to January 2022, obtained during an acoustic telemetry study (Chapter 7, this report). Water temperature obtained from HOBO loggers (Onset, HOBO 64K Pendant) at 4 to 7 meters water depth in Salling Sund (April to early August) and Livø Bredning (mid-August to January). Monthly mean water temperature (black square and line) was calculated from two-hourly records. Daily (blue cross and line) and monthly (red diamond and line) are daily mean air temperature in Thisted (DMI, 2022: https://www.dmi.dk/vejrarkiv/).

However, air temperature is more variable at sub-daily and daily scales than water temperature, and the offset between the two can vary with season, e.g. from 0.5 °C in December 2021 to 3.5 °C in July 2021 (Figure 3.1). Furthermore, changes in water temperature, may lag or precede air temperature changes, depending on weather and current circulation conditions.

Landing and fishing effort data

Monthly lobster landings (kg) and fishing effort as the number of active fishing boats in the commercial fishery, i.e. with recorded landings at auction, in the Limfjorden from 2010 to September 2022 were obtained from Fiskeristyrelsen (Figure 3.2).

Number of active fishing boats in the commercial fishery constitute the only available measure of fishing effort, even if partial. Fishing effort can vary in several ways not known that are not captured just by number of active commercial fishing vessels, such as:

1. The type and number of fishing gear, and number of hauls per boat, as well as landings of each commercial vessel.
2. Fishing effort data for the significant recreational fishery (number of vessels, type and number of fishing gear and hauls).
3. Information from fishing associations indicate that both the commercial and recreational fisheries in the last 5-10 years have often replaced lower efficiency gear, such as fyke nets, gill nets and trammel nets, with higher efficiency multi-pots (Chapter 8, this report), but the reverse has also occurred with increased use of lobster pots to counter higher catches of brown crabs in Nissum Bredning.

Data selection

Landing data from July and August during the closed period of the fishery when no fishing is allowed were excluded from analysis. In addition, landing data from January, February and at temperatures lower than 3.0 °C, when the fishery is almost entirely inactive were also excluded (Figure 3.2). September 2022 constituted an outlier with over 18,000 kg landed lobsters and accounting for 45.5% of landings in 2022 and was excluded from regression analysis but was included in the calculation of the standardized index ($RPUE_{m,}$ see definition below). In all other years, at least between 93.9% (2021) and up to 99.1% (2011) of total annual landings were included in the analysis.

Based on exploratory analysis of the data, temperatures for June and September were included as the means of May and June and the means of August and September temperatures, respectively. The rationale is twofold:

1. An offset between landing date and corresponding temperature date is inherent to the data and landings for any given month will include a variable proportion of catches from the previous month under different temperatures. Landing dates do not correspond to capture dates as soak times used in the fishery (usually from 5 and 10 days) introduce a lag in landing date relative to capture date and corresponding temperature. The impact of such offset is expected to be larger when landings are largest (i.e. June) and when temperature change span 10–12 °C and lobster activity and catchability changes the most (Figures 3.1 and 3.2; Brandford, 1979; Smith et al., 1999; Molland et al., 2011). June landings were assumed to also reflect May temperature however, October landings were not found to reflect previous month temperatures possibly due to the timing of when water temperature drops below 10-12 °C (Figure 3.2; Chapter 7, this report).
2. Since there is no prohibition to deploy fishing gear during the closed period, the commercial fishery deploys gear as early as the second week of August to occupy fishing grounds and

maximize catches. For instance, landings in the first four days of September 2019 represented 36.4% of that month landings, a common occurrence in September (Fiskerikontrol), and must come from gear deployed in August. Therefore, landings in September include a significant fraction that is captured from mid-August and is related to lobster catchability and temperature in August.

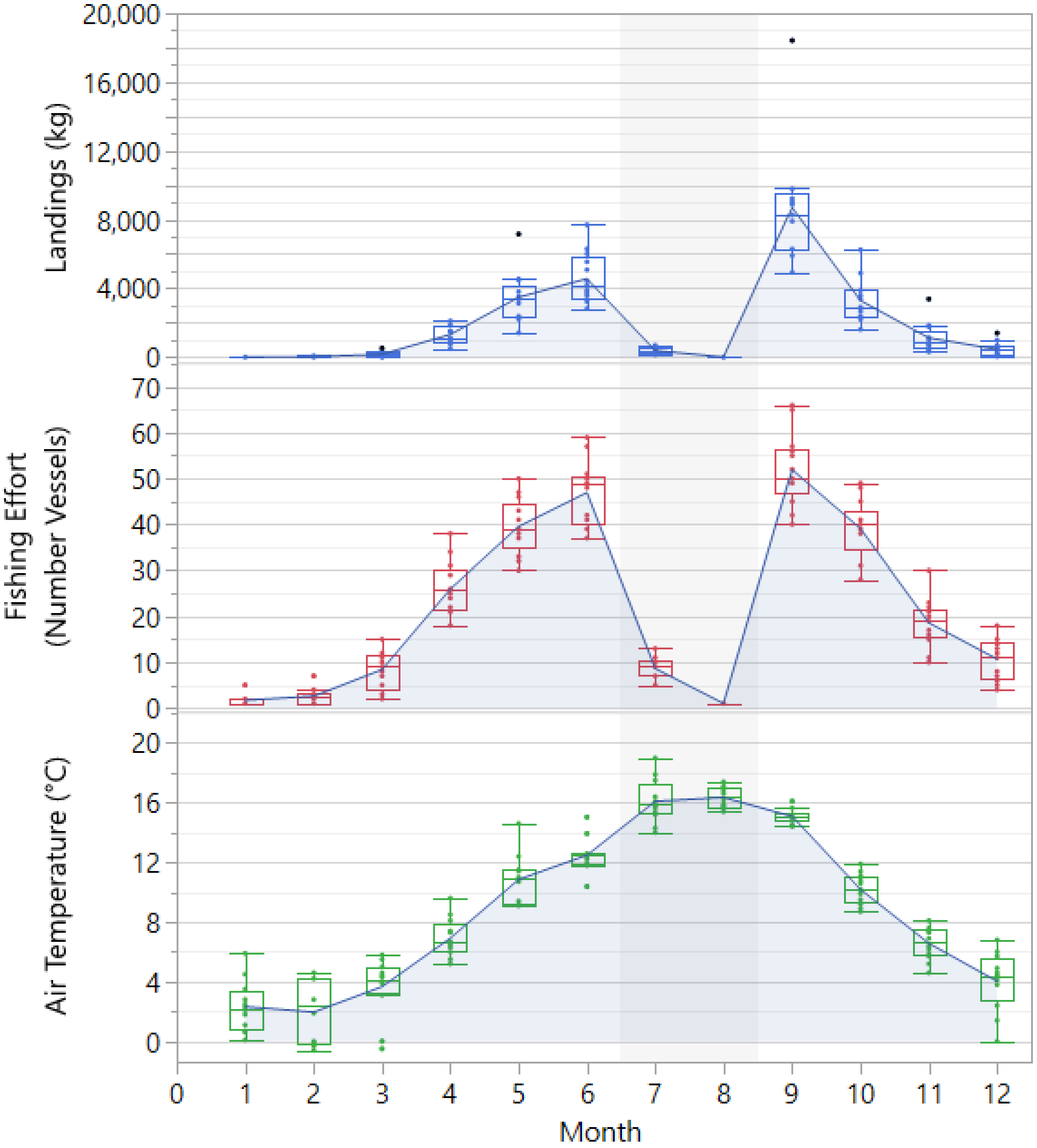

Figure 3.2. Monthly lobster landings (top) and fishing effort as number of active fishing vessels (middle) in the commercial fishery in the Limfjorden (2010 to September 2022, Fiskeristyrelsen) and monthly air temperature in Thisted (bottom; 2011 to September 2022, DMI). Grey band marks the closed period. Box/plots show quartiles, minimum and maximum. Landings outliers from 2018 (May) and 2022 (September, October, November, and December).

Data analysis: LPUE and RPUE

Landings-per-unit of effort ($LPUE_m$) were produced from monthly landings (L_m) per monthly fishing effort (i.e. number of active commercial lobster fishing vessels) to account for the effect of fishing effort.

Annual landings-per-unit of effort ($LPUE_a$) were obtained by dividing annual landings (L_a) by annual fishing effort (i.e. number of active commercial lobster fishing vessels). L_m and $LPUE_m$ data were square root transformed for linearity relative to air temperature and number of fishing vessels (Figures 3.3, 3.4 and 3.5).

The catchability, and thus catch rate, of lobsters will vary strongly seasonally due particularly to temperature (e.g. McLeese and Wilder, 1958; Smith et al., 1999) but also biological factors (e.g. moulting or mating). $LPUE_m$ was standardized using general linear model (GLM) least squares regression, with LPUE as the response variable and air temperature, year and month as explanatory variables. Temperature was included to account for its effect on catchability. Year must be an explanatory variable in the model, even if not statistically significant, if the purpose of standardizing catch and effort data is to detect trends over time (Maunder and Punt, 2004). Month was included to account for seasonal effects and the interaction year * month was included to account for interannual variation in biological and temperature effects on the seasonal pattern of catchability/catch rates (e.g. Tully et al., 2006).

Residuals of the linear fit ($RPUE_m$) represent variability in $LPUE_m$ unrelated to temperature, which reflect other factors: i.e. error, variability in the abundance of the population and lobster biology (e.g. migration, moulting, mating or reproduction). An annual index of residuals-per-unit-effort ($RPUE_a$) was obtained by averaging $RPUE_m$.

L_m, L_a, $LPUE_m$, and $LPUE_a$ indices were standardized by subtracting the mean and dividing by 1 standard deviation. L_m, L_a, $LPUE_m$, and $LPUE_a$ lower or higher than 0 indicate landings and landings per boat lower or higher than average since 2010, respectively. $RPUE_m$ and $RPUE_a$ lower or higher than 0 indicate landings-per-unit effort (i.e. per boat) lower or higher than explained by temperature.

3.3 Results

Landings, temperature, and fishing effort

Monthly landings of lobsters in the Limfjorden (L_m) showed a clear non-linear variation with both mean air temperature and fishing effort, i.e. number of fishing vessels (Figure 3.3). The high L_m of over 18,000 kg in September 2022 was considered an outlier and excluded from further regression analysis. Once square root transformed, L_m was strongly positively correlated to fishing effort and mean air temperature (Figure 3.3): $r^2 = 0.840$, $p < 0.0001$ and $r^2 = 0.848$, $p < 0.0001$, respectively ($n = 95$ for both), with increased landings at higher fishing effort and higher temperature. However, such relationship masks significant covariation between fishing effort and temperature (Figure 3.4), which are strongly positively correlated ($r^2 = 0.771$, $p < 0.0001$, $n = 95$).

Landings-per-unit-effort (LPUE)

Similar to landings, monthly landings-per-unit effort ($LPUE_m$) showed a clear non-linear relationship with air temperature, and once squared root transformed a strong positive correlation with air temperature (Figure 3.5): $r^2 = 0.688$, $p < 0.0001$, $n = 94$.

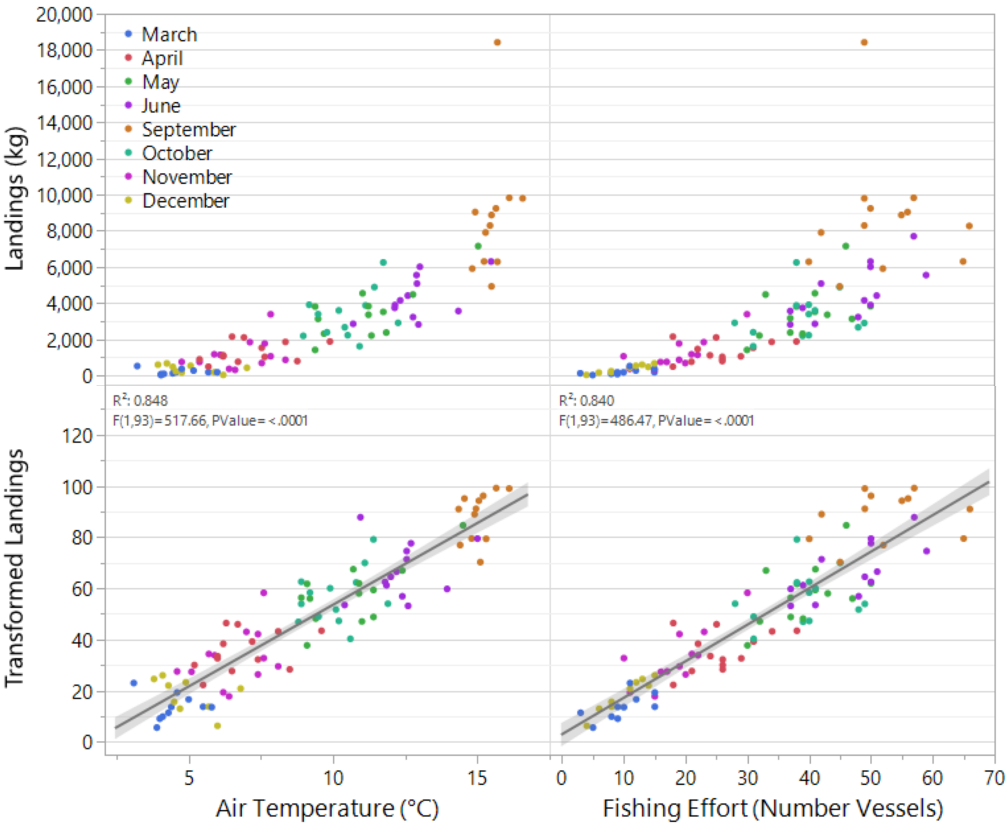

Figure 3.3. Monthly landings (top, L_m) and square root transformed landings (bottom) versus monthly air temperature and fishing effort (number of fishing vessels). Landings of over 18,000 kg in September 2022 was an outlier and excluded from regression analysis.

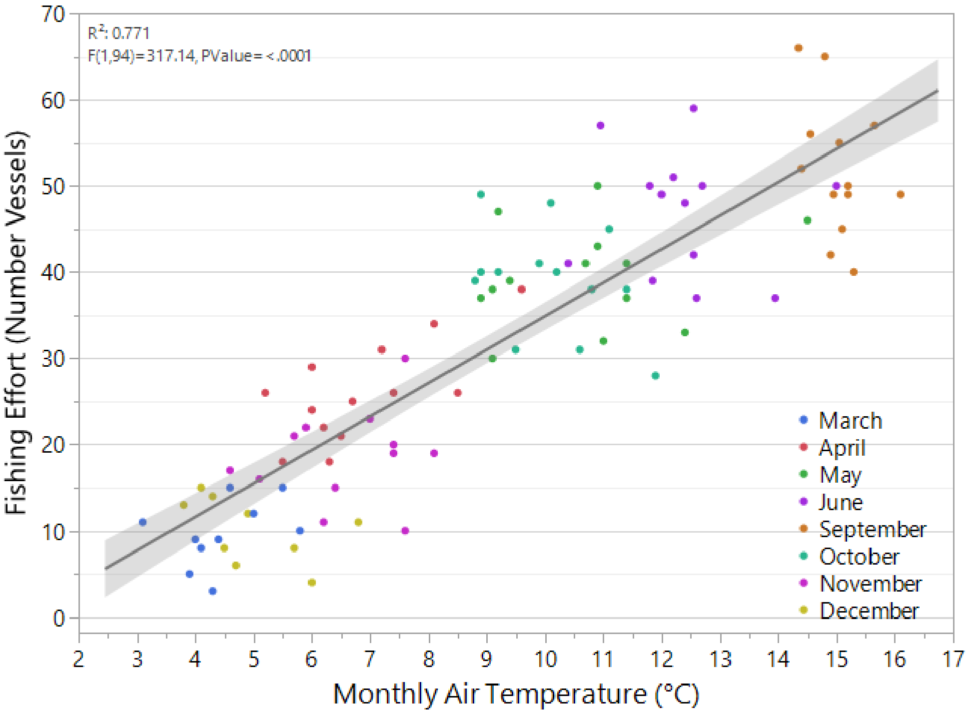

Figure 3.4. Monthly fishing effort (number of vessels) and monthly air temperature. The linear model was significant at *$p < 0.0001$* and temperature explained 77.1% of variability in fishing effort (n = 95). Shaded areas are 95% confidence intervals of fit.

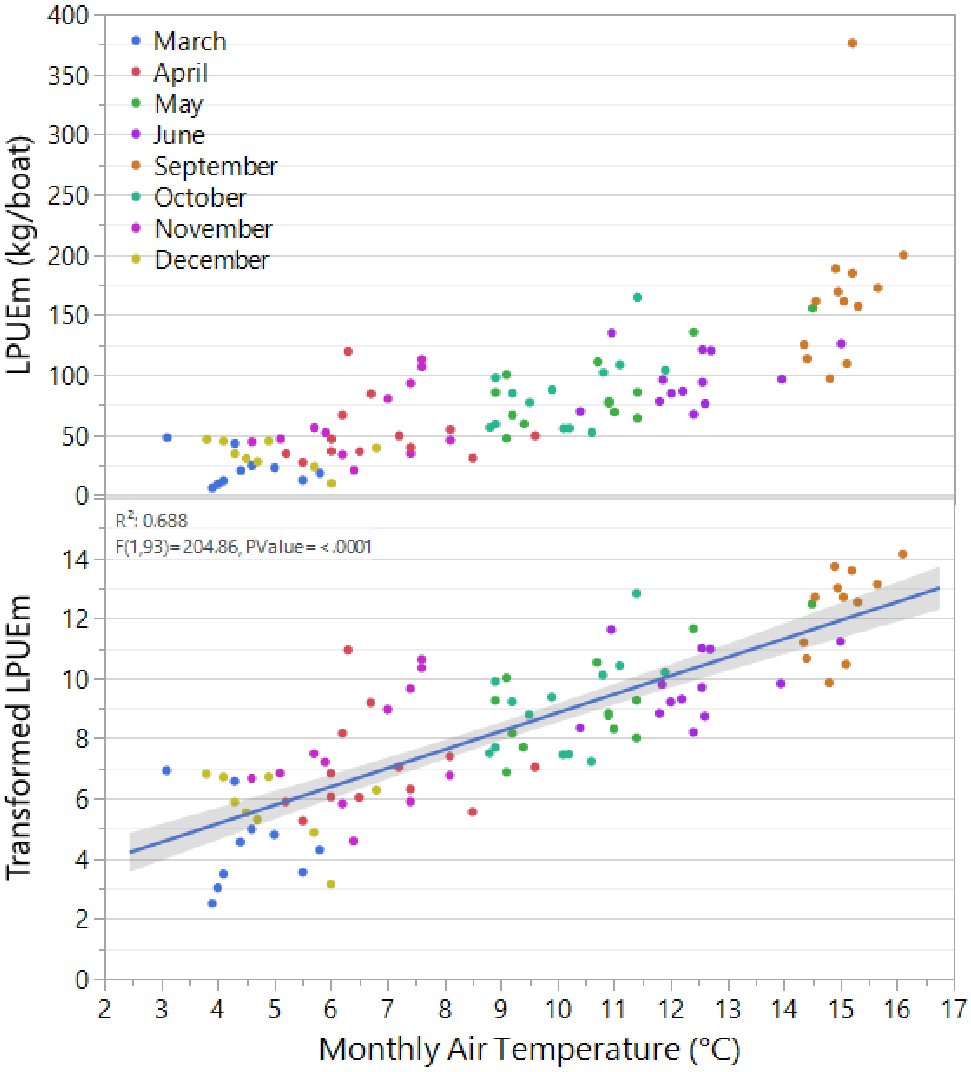

Figure 3.5. Monthly landings LPUE$_m$ (top) and square root transformed LPUE$_m$ (bottom). GLM least square regression between LPUE$_m$, (square root transformed) and air temperature. The linear model was significant at $p < 0.0001$ and explained 68.8% of variability in monthly lobster landings (n =94). Shaded areas are 95% confidence intervals of fit. Months are identified by different colours.

The GLM least square regression model between LPUE$_m$ (square root transformed) and monthly air temperature, year, month and year * month interaction as explanatory variables was significant (F(1,94) = 68.30, $p < 0.0001$) and explained 75.2%% of the variance at $p < 0.0001$ level, and all variables were significant at a significance level of $p < 0.05$ (Table 3.1). Data were homoscedastic and residuals normally distributed (Anderson-Darling $A^2 = 0.303$, $p = 0.596$).

Monthly RPUE

While LPUE$_m$ shows clear seasonality with higher values in the warmer late spring to early autumn months. By removing the temperature effect on lobster catchability, RPUE$_m$ (i.e. standardized LPUE$_m$) a clear seasonal cycle is no longer present (Figures 3.6 and 3.7), and also fishing season had no effect on RPUE$_m$ (ANOVA, F(1,94) = 0.103, $p = 0.749$).

Table 3.1. GLM Linear regression analysis summary for lobster monthly landings-per-unit effort (LPUE_m, square root transformed) predicted from monthly mean air temperature, year, month and year * month interaction. RMSE is root mean square error.

	N	*r*	*r^2*	*Adj. r^2*	*p-value*	*RMSE*
	94	0.867	0.752	0.741	< 0.0001	1.36
Anova	df	*F*	*P*			
	1/94	68.303	< 0.0001			
	Estimate	*SE*	*-95% CI*	*+95% CI*	*t*	*p-value*
Intercept	-183.202	79.018	-340.18	-26.22	-2.32	0.0227
Temperature	0.6095	0.0391	0.5319	0.687	15.61	< 0.0001
Year	0.0919	0.0392	0.0140	0.170	2.34	0.0212
Month	0.1008	0.0453	0.0108	0.191	2.22	0.0286
Year*Month	0.0488	0.0130	0.0229	0.075	3.74	0.0003

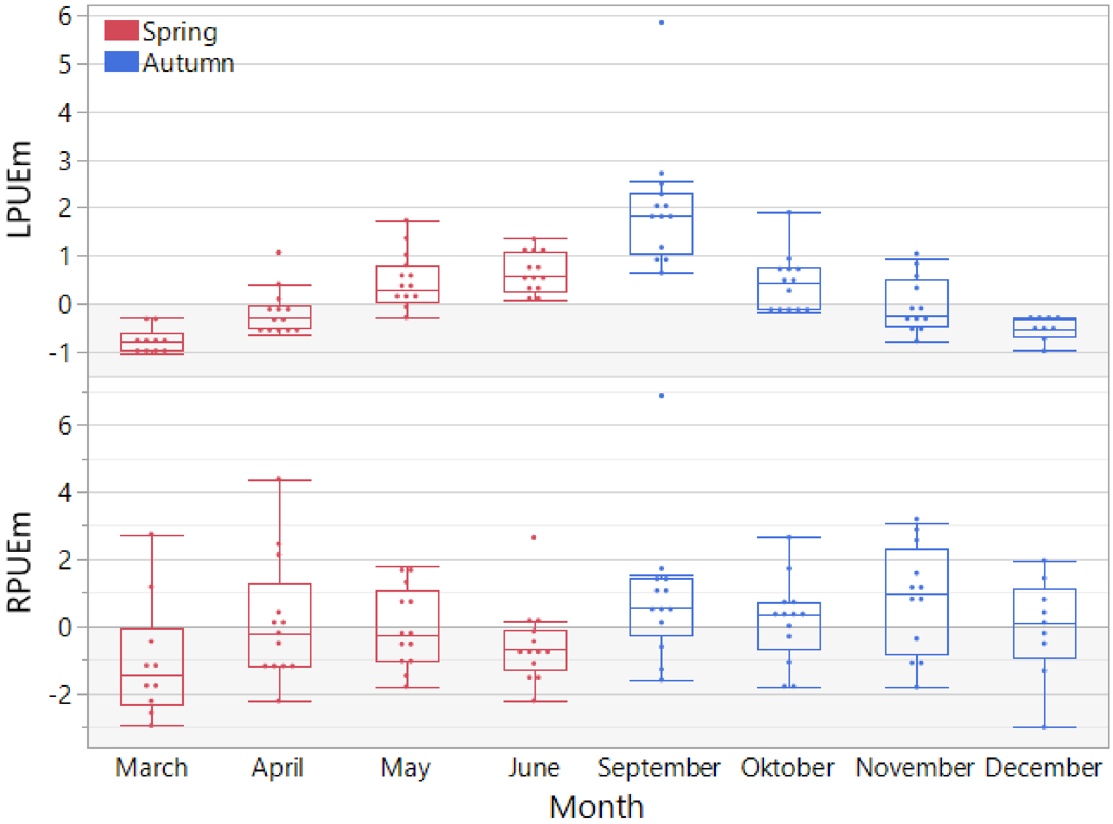

Figure 3.6. Boxplots of monthly (from top): i) LPUE_m and RPUE_m. LPUE_m index was standardized to mean of zero. Grey bands indicate (negative) values below average.

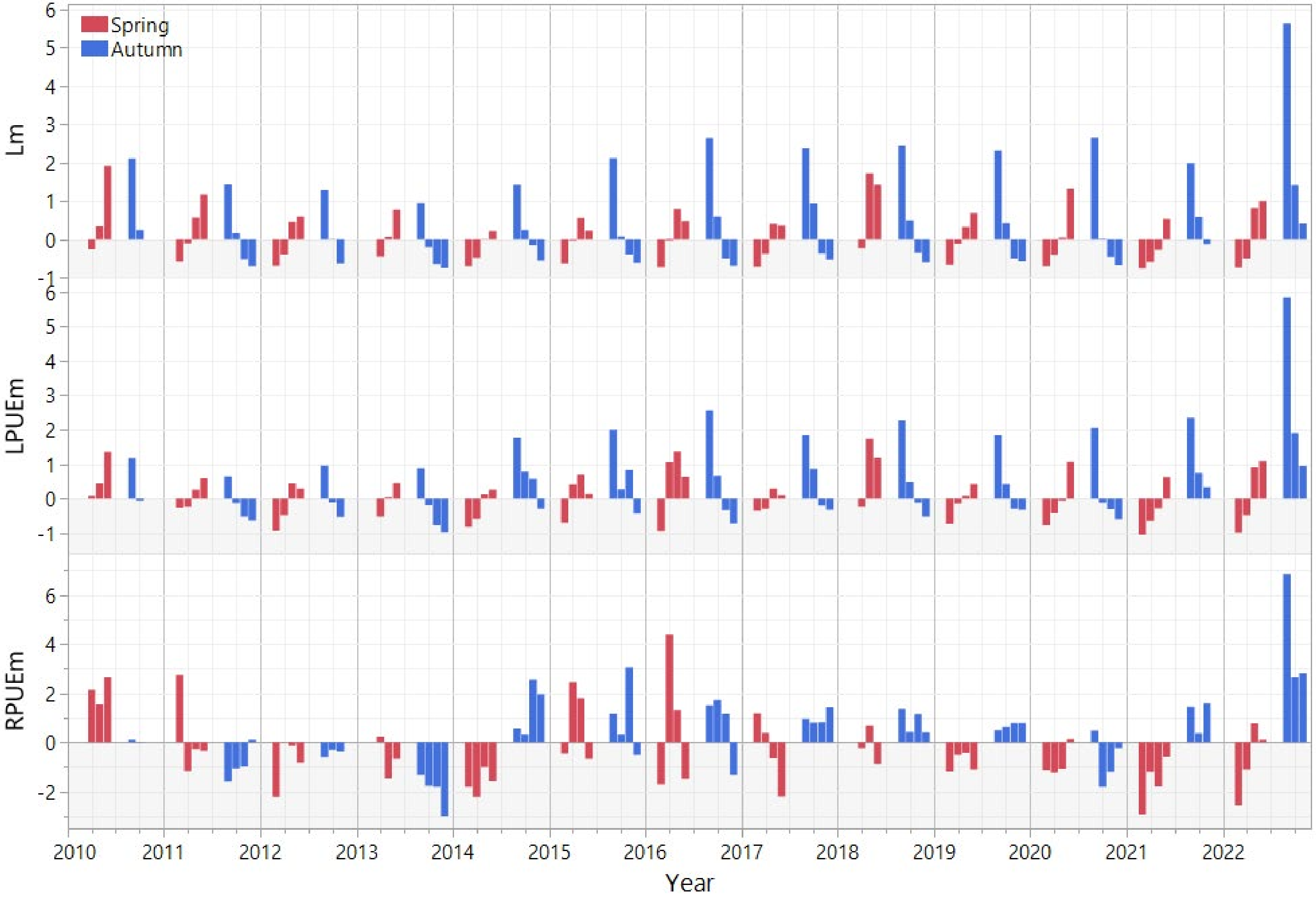

Figure 3.7. Monthly timeseries of L_m (top) $LPUE_m$ (middle) and $RPUE_m$ (bottom). L_m and $LPUE_m$ indices were standardized to means of zero. Grey bands indicate (negative) values below average.

$RPUE_m$ indicates if $LPUE_m$ was lower or higher than predicted from temperature, if negative or positive respectively, and thus if lobster abundance was lower or higher. $RPUE_m$ had a long period of negative values between spring 2011 and summer 2014, followed by a period of generally positive values between autumn 2014 and early autumn 2018 (Figure 3.7). Since 2017, $RPUE_m$ was markedly negative in the autumn 2020 and spring 2021, and markedly positive in 2022, particularly in the autumn (Figure 3.7). Such patterns cannot be observed in L_m and $LPUE_m$, which reflect the seasonal changes in temperature.

In autumn 2022, the highest L_m and $LPUE_m$ on record for September (by 87%), October, November and December were observed, which originated from the significant recruitment of a juvenile cohort from late spring 2022 (Chapter 4, this report). $RPUE_m$ also had its highest values for September, October and November in 2022 (Figure 3.7).

Annual indices of lobster abundance

$RPUE_a$ showed two multi-year periods with clear negative values between 2011 and 2014 and later between 2019 and 2021 (Figure 3.8). Between 2015 and 2018 $RPUE_a$ was positive, with its highest values in 2010, 2015 and 2022.

$LPUE_a$ had lower than average but stable values between 2011 to 2014, then with an increasing trend to a maximum in 2018 followed by a decrease to lower but still higher than average between 2019 to 2021, and then record high values in 2022 (Figure 3.8).

L_a decreased to below average values from 2011 to 2014/2015, then increasing to a maximum in 2018 and followed by a decrease to below average values in 2021 and then record high values in 2022 (Figure 3.8).

Fishing effort, as number of active fishing vessels per year, decreased significantly from over 90 vessels in 2010 and 2011 to a minimum of 55 vessels in 2014. An increase then occurs to just over 70 vessels by 2019 and 2020, roughly in parallel but lagging the increasing trend in L_a and $LPUE_a$ from 2014 to 2018. In the last two years, 2021 and 2022, fishing effort decreased again to around 60 vessels.

3.4 Discussion

Assessment of the Limfjorden lobster population and management of its fishery presents several challenges linked both to a general lack of data and the complex specificities of the fishery. Namely, it is a data-poor (ICES category 5) and recent fishery (>10 tons from 2009) with both significant commercial and recreational fishing, for which no limitations in access exist apart from a valid fishing licence.

The only available data on the fishery is restricted to official reported landings, which exclude juveniles and berried females, and the number of active fishing vessels in the commercial fishery. No limitation or registration of fishing effort exist, with only recreational fishing limited to 6 units of fishing gear per fishermen. However, illegal, unreported, and unregulated fishing in both the commercial and recreational fishing are often mentioned by stakeholders as being significant. Exceptionally in European lobster fisheries, the Limfjorden fishery allows the use of several types of fishing gear with different efficiency and catchability, such as gill and trammel nets, pots, multi-pots and fyke nets.

Therefore, several unknowns are present that may significantly affect LPUE, e.g. a change in fishing effort due to variation in the amount or type of gear used per boat, that neither fishing behaviour and effort of individual boats are considered, or changes in IUU fishing (Illegal, unreported and unregulated) affecting landings. The fundamental assumption of this study is that in spite of such caveats, LPUE from the commercial lobster fishery preserves a signal related to lobster abundance.

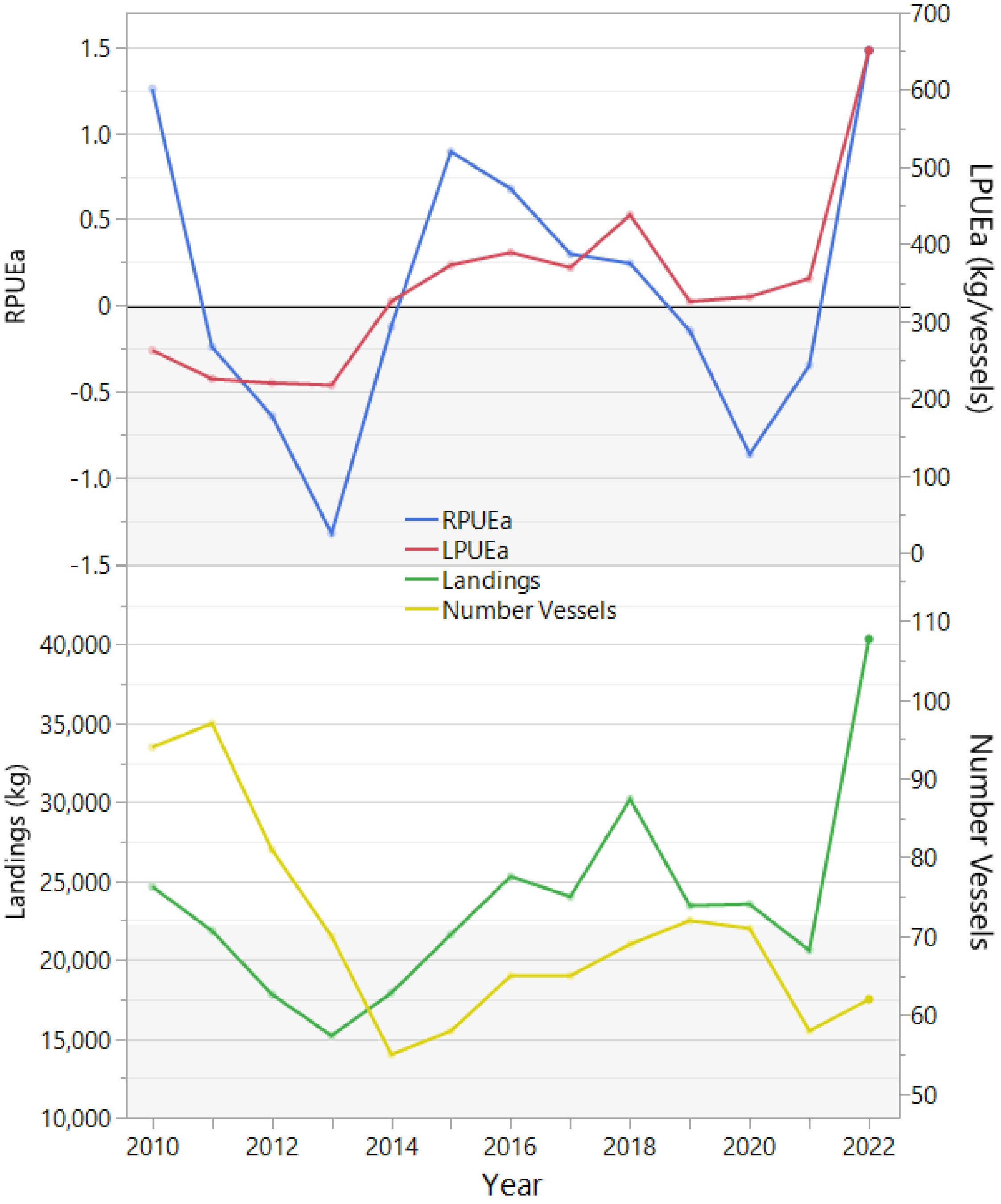

Figure 3.8. Annual timeseries of RPUE$_a$ (blue, top), LPUE$_a$ (red, top, kg/vessels), Landings (green, bottom, kg) and number of fishing vessels (yellow, bottom). For LPUE$_a$, landings, and number of fishing vessels, grey bands indicate (negative) values below the 2010-2021 average. For RPUE$_a$ grey band indicates an LPUE smaller than predicted from temperature.

Similarly to other homarid fisheries (e.g. Dow et al., 1975; Dow 1977), a significant and strong relationship between commercial landings, effort and temperature was observed in the Limfjorden reflecting a significant effect of temperature on catchability and on LPUE (Figure 3.3). Temperature and fishing effort covaried strongly, reflecting an indirect effect of temperature on fishing effort acting through temperature related changes in lobster activity and catchability: fewer boats fish lobsters in months with reduced lobster catchability and lower temperatures, and more boats fish lobsters in months with increased lobster catchability and higher temperatures (Figures 3.2 and 3.4). RPUE indicates if LPUE was lower or higher than predicted from temperature, if negative or positive respectively, not if LPUE absolute values were lower or higher.

RPUE$_m$ and RPUE$_a$ identified periods interpreted as having reduced and increased lobster abundance. Namely, RPUE$_m$ indicated reduced lobster abundance from spring 2011 to spring 2014, followed by a period of mostly increased abundance from autumn 2014 to autumn 2018 (Figure 3.7). Since 2014 and except in 2020, autumn RPUE$_m$ were almost always positive and higher than predicted by temperature. Spring RPUE$_m$ by contrast were mostly negative and lower than predicted by temperature since 2017.

The recent seasonal pattern of RPUE$_m$, positive in autumn and negative in spring, may reflect changes in abundance and recruitment into the fishery as evident in autumn 2022, but may also reflect reduced catchability in recent springs from hatching, mating and moulting, which are expected to occur in spring-summer (e.g. Agnalt et al., 2007; Whale et al., 2013). The main period of moulting was reported by fishermen during the project to occur earlier in recent years starting already in June (personal communications).

Variations from year to year in the abundance of a stock will result from a balance between recruitment and growth on one side and fishing and natural mortality on another. Once past the early juvenile stages, European lobsters have long longevity and low natural mortality, with few predators once mature apart from intra-species predation (e.g. Wahle et al., 2013 for a review on its biology).

RPUE$_a$ indicated two clear negative periods interpreted as reduced lobster abundance between 2011 and 2014 and between 2019 and 2021 (Figure 3.8). A decreasing trend followed a significant maximum in RPUE$_a$ in 2015 until 2020, with exceptionally high RPUE$_a$ in 2022 (Figure 3.8). Such variation in abundance, as indicated by RPUE$_a$, thus likely results from low fishing effort in 2014 and 2015 and good recruitment in 2015 combining to produce a significant maximum in abundance in 2015, which was followed by a multi-year period when recruitment and growth were unable to compensate for fishing mortality resulting in a decreasing trend in abundance between 2015 and 2020 (Figure 3.8). Even though landings increased in parallel with increasing fishing effort from 2014 to 2018, and were above average for most of this period, once the temperature effect on catchability was removed lobster abundance decreased likely due to overfishing (Figure 3.8). The recruitment into the fishery of a strong juvenile cohort in autumn 2022, which was monitored since summer 2020 (Chapter 4, this report), then replenished the stock resulting in exceptionally high abundance and catches.

By removing variability determined by annual and seasonal differences in temperature, standardized RPUE infers changes in lobster LPUE that result from other factors affecting catchability, i.e. lobster abundance but also lobster biology (e.g. migration, moulting, mating or reproduction), and thus provide an improved and more robust index of lobster abundance for the lobster Limfjorden fishery than landings or LPUE.

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4. Size structure of the Limfjorden European lobster (*Homarus gammarus*) population 2020–2022

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4.1 Rationale

Size structure is an important tool in fishery stock assessments, providing information about population demographics and dynamics and contributing to maintain the sustainability of an exploited population. Changes in size have implications for the productivity, fate and resilience of fished populations, stock dynamics and the overall structure of ecosystems (Andersen et al., 2019). Fishing is always size selective, and the size distribution of an exploited population will shift toward smaller sizes and younger ages by the preferential removal of large and old, high value individuals, which can result in population instability and increased sensitivity to deleterious environmental conditions, trophic interactions and human impacts (e.g. Planque et al., 2010; Audzijonyte et al., 2013). For instance, the reproductive value of large, highly fecund female lobsters is not linearly proportional to body length, but instead increases as a cube of body length (Tully et al., 2001; Agnalt 2008), and thus its removal has a disproportionate impact on the reproductive capacity of the population.

Size or length frequency data of the catch is a very common and cost-effective source of information in many data-limited fisheries, required for size-based models in fisheries management (e.g. Beverton and Holt, 1957). Size-based indicators (SBI), such as mean length, evenness of size classes, size at first capture or landing, upper 95th percentile of size frequency distribution, are metrics that numerically summarize the size distribution of a population and are commonly used to trace demographic changes in fished populations or communities because of their responsiveness to fishing pressure (e.g. Shin et al., 2005). For instance, mean length of the catch/landings or size spectrum are inversely correlated with fishing mortality (e.g. Beverton and Holt, 1957; Gislason and Rice, 1998).

Lobster fishing in the Limfjorden has increased since early 2000’s after a period of 40 years with virtually no landings. Over the last 12 years lobster landings reached similar levels to historical pre-1960´s landings but have fluctuated by over 100% (Chapter 2, this report). The lobster fishery is data-poor with data available only on commercial landing and thus management of the fishery would greatly benefit from timeseries of biological indicators (e.g. SBI, size-based indicators).

The aim of this task was to evaluate the size structure of lobsters in the Limfjorden through SBIs: mean length, size at first capture/landing and the upper 95th percentile. Data was obtained from independent surveys and from catch reports from on-board observers in the commercial and recreational fisheries. In this task, lobster size was compared between a protected area with low fishing mortality and fished areas; the current size structure (i.e. spring 2022) across the western and central Limfjorden was assessed; the growth of a juvenile cohort and its recruitment into the fishery from spring 2022 was followed since 2020.

4.2 Methods

Catch data

Size and sex data were obtained from catches in both the commercial and recreational fisheries and from fishery independent surveys in 2020, 2021 and 2022. Carapace length (CL) was measured to the nearest mm from the back of the eye socket to the posterior edge of the cephalothorax. Lobsters were sexed based on morphological differences in the first pair of pleopods/swimmerets. During the fishery independent surveys in 2020 and 2021 lobsters were weighed.

Catch reports were provided by recreational fishermen taking part in a voluntary report program (Nøglefiskere) in the fishing grounds off northern Mors and Ejerslev Røn during the spring and autumn fishing seasons of 2020, 2021 and 2022 (black dots in Figure 4.1).

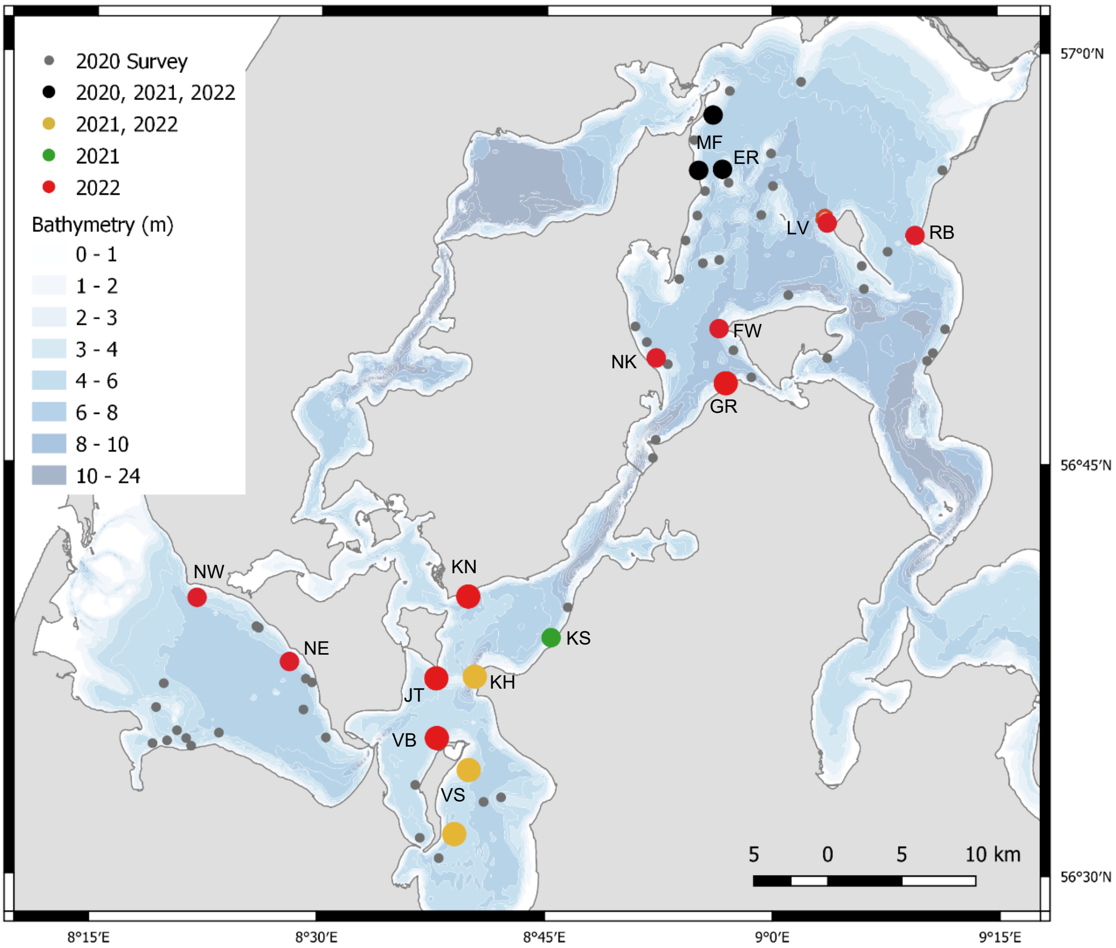

Figure 4.1. Location of fishing grounds where recreational fishermen (black dots), observer reports in the commercial fishery (red, yellow and green dots for different years) and research surveys (grey dots and LV) provided catch data. Fishing grounds referred to in the text. Løgstør: Mors/Fegge – MF, Ejerslev Røn – ER, Livø – LV and Rønbjerg – RB; Sønder-Salling: Fur W – FW, Grynderup – GR and Nykøbing – NK; Kås: Kås Syd – KS, Kås N – KN and Kås Hoved – KH; Venø Bugt: Jegind Tap – JT and Venø Bugt – VB; Venø Sund: Venø Sund – VS; Nissum: Nissum West – NW and Nissum East – NE.

Catch data collected by on-board observers in the commercial fishery was obtained in four fishing grounds in the 2021 autumn fishing season and 15 fishing grounds in the 2022 spring fishing season, covering most of the main fishing grounds in different basins of the western and central Limfjorden (Figure 4.1).

Catch data obtained in the fishing gear trials (Chapter 7, this report) and from two research surveys was obtained outside the fishing seasons in the summers of 2020 and 2021 (Petersen et al., 2022), the former across most of the western and central Limfjorden and the latter only in the Livø stone reefs marine protected area (Figure 4.1).

Table 4.1. Summary of lobster measured in the Limfjorden in the springs of 2020, 2021 and 2022 per fishing gear, season and year, fishing ground and presence of escape vents or mesh panels (mm). n is sample size.

Gear/Year	Ground	Escape Size	N	Gear/Year	Ground	Escape Size	N
Multi-pots				*Pots*			
Spring 2020	Mors/Fegge	None	95	Summer 2020	Limfjorden	None	213
	Ejerslev Røn	None	48	Spring 2021	Kås S	None	265
Autumn 2021	Mors/Fegge	None	73		Kås Hoved	None	107
	Ejerslev Røn	None	128		Venø Sund W	None	147
Spring 2021	Mors/Fegge	None	21	Summer 2021	Livø	None	754
	Ejerslev Røn	None	669	Spring 2022	Kås Hoved	None	153
	Kås S	None	514		Venø Sund W	None	73
	Kås Hoved	None	98		Jegind Tap	None	38
	Venø Sund W	None	155		Venø Bugt E	None	75
Autumn 2021	Mors/Fegge	None	103		Fur W	50	11
	Ejerslev Røn	None	759		Nissum W	54	185
	Kås S	None	461		Nissum W	60	83
Spring 2022	Mors/Fegge	None	65		Nissum E	54	38
	Ejerslev Røn	None	267		Nissum E	60	25
	Livø	None	179	*Fyke Net (Eel)*			
	Rønbjerg	None	197	Spring 2021	Kås S	None	130
	Nykøbing M	None	73		Kås Hoved	None	26
	Fur W	50	401		Venø Sund	None	82
Autumn 2022	Mors/Fegge	None	58	Autumn 2021	Fur W	None	107
	Ejerslev Røn	None	104	Spring 2022	Fur W	50	334
Nets					Fur W	None	237
Spring 2020	Mors/Fegge	None	69		Grynderup	50	161
	Ejerslev Røn	None	106		Venø Sund	None	99
Autumn 2020	Ejerslev Røn	None	21	*Fyke Net (Cod)*			
Spring 2021	Kås S	None	167	Autumn 2021	Venø Sund	57	109
	Kås Hoved	None	37	Spring 2022	Kås N	None	772
	Venø Sund W	None	161		Kås N	45	178
					Venø Sund	None	113

Fisheries-based data was obtained from different types of gear that are allowed in the Limfjorden lobster fishery ranging from lobster pots, multi-pots (aka. Kinaruser), gill and trammel nets (nets), and fyke nets for eel and cod (Table 4.1). Furthermore, survey catch data was obtained from lobster pots and also reported in Table 4.1.

Data from fishing gear with escape vents or panels was excluded from analysis when comparing protected to fished areas. Since for some areas (e.g. Nissum W and E, and Kås N) data was only available from gear with escape vents, such data was included in the analysis when assessing the landed fraction (i.e. > 87 mm CL), size in spring 2022, and juvenile cohort growth.

Size-based indicators (SBI)

Several size-based indicators (SBI) were calculated from the data (e.g. Shin et al., 2005; ICES 2012, 2017; Froese et al., 2018). SBIs are specific to the type of gear used and how it is set in a specific sampling design, and thus a bias may occur due to any factor that alters lobster behaviour (e.g. seasonal reproduction or moulting) but importantly due to gear selectivity causing significant and systematic under- or over estimation of specific sizes (e.g. Shin et al., 2005).

Size at first capture (L_C), is the length at which 50% of the population is vulnerable and retained by fishing gear and it thus gear specific. L_C is often determined as the length at 50% the number of the first frequency peak or size class mode (ICES,2012), assumed to represent the length when all individuals are vulnerable and captured by the gear (L_p). L_X is the smallest length when individuals become vulnerable to fishing gear (L_X).

Mean length of catch (L_m) quantify the relative abundance of large and small individuals and mortality and is usually determined as the mean length of individual larger than L_C or larger than MLS.

Length of the largest 5% individuals (L_{95}) quantifies the depletion of the largest individuals in a population. L_{95} describes better than maximum length (L_{max}) the abundance of large individuals in the population.

In a similar concept, although not an SBI, median length of landings at which 50% of landings are obtained (L_{50L}) and mean length of landings (L_{mL}) reflect the relative abundance of large and small individuals in landings. Data from gear with escape vents or mesh were excluded for landing data.

Evenness was determined as the Pielou's evenness index J', which measures the evenness in the distribution of individuals among size classes: $J' = H / \ln(S)$ where, H is equivalent to the Shannon Diversity Index, but in which species are replaced by size classes, and S is the total number of size classes. J' ranges from 0 to 1 and 1 indicates complete evenness.

As length-frequency data deviated from normal distribution, non-parametric Kruskal-Wallis test and Dunn's pairwise test with Bonferroni correction were used to evaluate significant differences in length-frequency data between areas (i.e. if one area had larger or smaller lengths than other areas), while Kolmogorov-Smirnov test for equal distribution was used to evaluate for significant differences in length-frequency distributions (cumulative distribution functions) , $D(35) = 0.257$, $p = 0.168$)

4.3 Results

Lobster size: Length and weight

Allometric relationships were established between total length (TL), carapace length (CL) and weight (W) to permit the interconversion of length and weight measurements for the Limfjorden lobster population.

TL and CL of both female and male lobsters showed strong positive correlations, $r^2 = 0.969$ ($p < 0.0001$, n = 187) and $r^2 = 0.981$ ($p < 0.0001$, n = 291), respectively.

The linear regressions between CL and TL of female and male lobsters were significantly different ($F = 12.539$, $p = 0.0005$) and are thus presented separately (Figure 4.2).

Female lobsters ($F(1,185) = 5826$, $p < 0.0001$, RMSE = 6.79):

$$TL = 8.591\ (\pm 3.04\ SE) + 2.678\ (\pm 0.35\ SE) * CL$$

Male lobsters ($F(1,289) = 15012$, $p < 0.0001$, RMSE = 6.72):

$$TL = 16.927\ (\pm 1.85\ SE) + 2.536\ (\pm 0.021\ SE) * CL$$

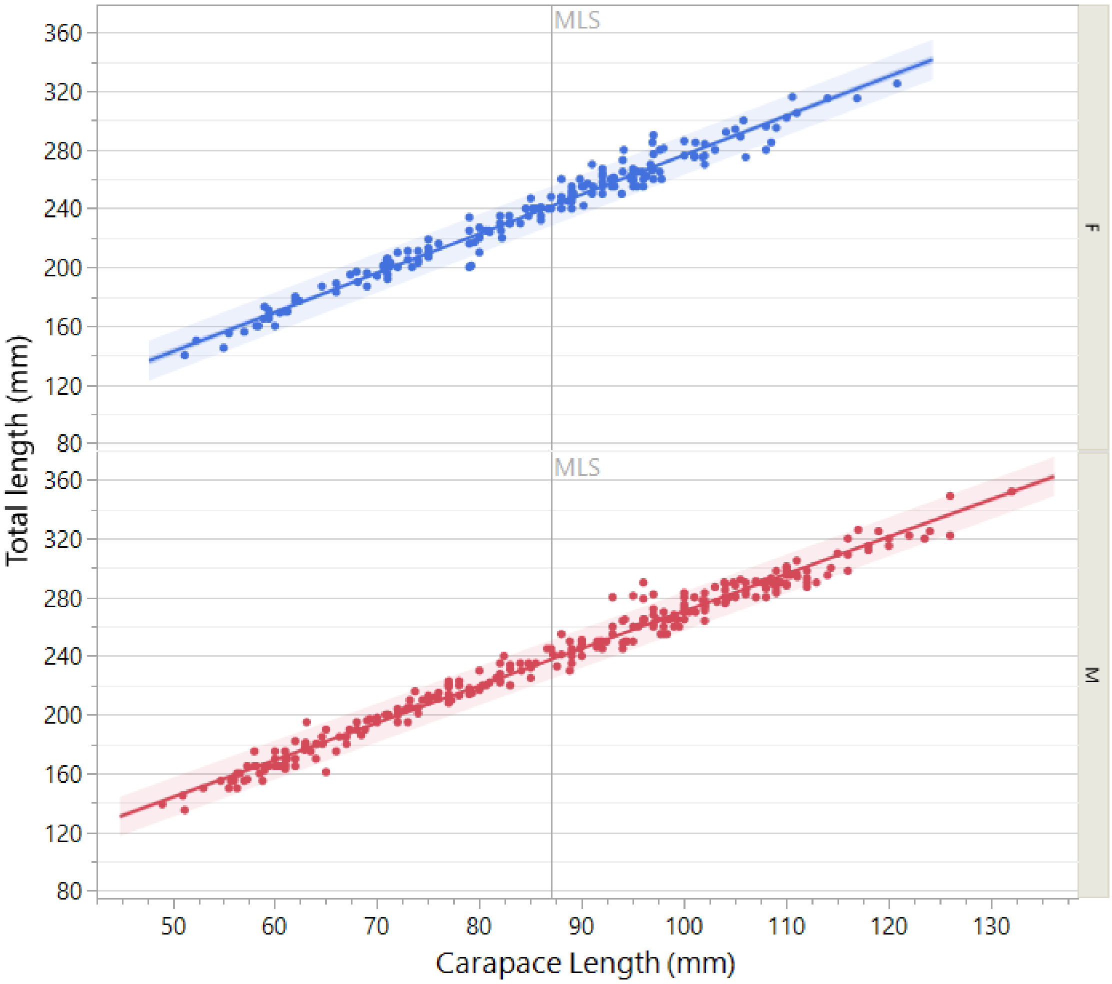

Figure 4.2. Carapace and total length regression for female and male lobsters in the Limfjorden. Shaded areas are 95% CI of fit (dark) and 95%CI if prediction (light). F – females and M – males. Grey line is minimum landing size (MLS).

The weight and length relationships in female and male lobsters in the Limfjorden were found to be described by allometric power equations (Figure 4.3):

Female lobsters ($r^2 = 0.836$):

$W = 0.0051989\ (0,\ 0.00814\ \text{CI}) * CL^{\ 2.5697(2.384,\ 2.723\ \text{CI})}$

Male lobsters ($r^2 = 0.903$):

$W = 0.00036475\ (0,\ 0.0017\ \text{CI}) * CL^{\ 3.1855(3.001,\ 3.339\ \text{CI})}$

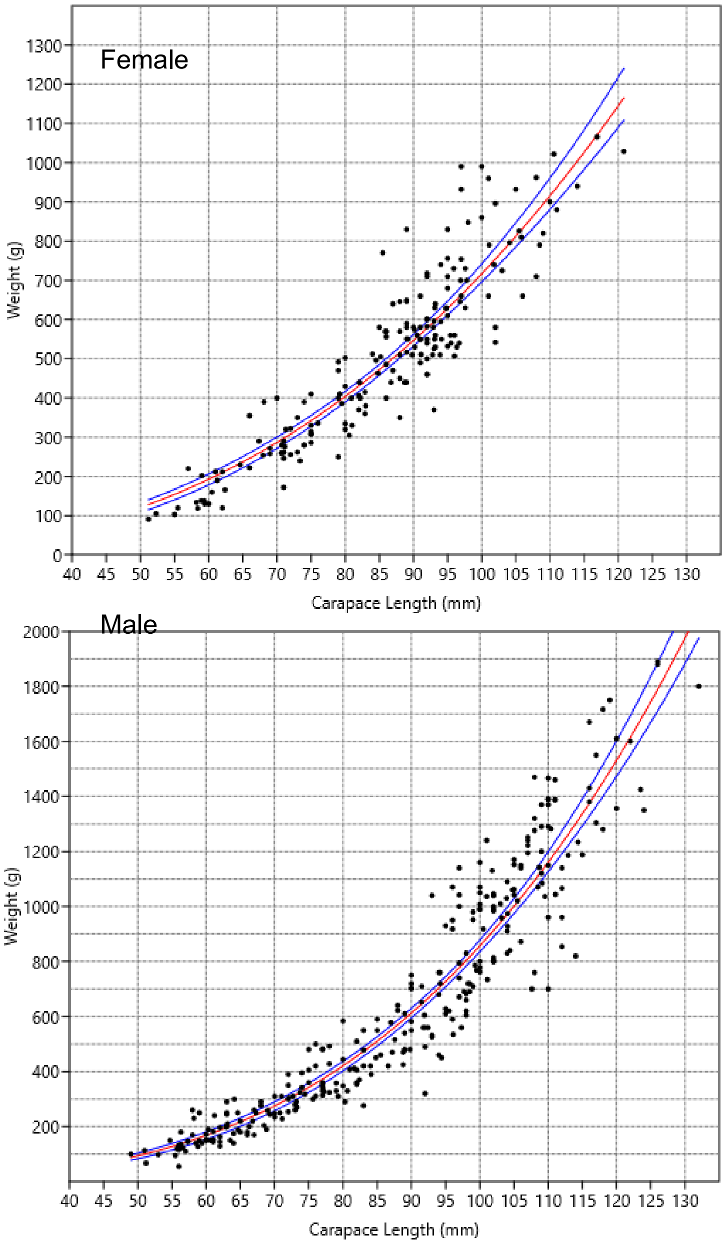

Figure 4.3. Weight and carapace length allometric relationships for female and male lobsters in the Limfjorden. Blue lines are 95% CI of fit. F – females and M – males.

Catches and length

Analysis of variance showed that CL was different according to sex and fishing gear type, generally larger in male lobsters except in eel fyke nets (Table 4.2), and also that CL of female and male lobsters varied differently with fishing gear type (Table 4.2). However, for the purposes of all SGIs (i.e. L_x, L_C, L_M, L_{95} and L_{max}) analysis were performed with sex aggregated (Table 4.3).

Table 4.2. Analyses of variance of the effects of sex and type of fishing gear on carapace length.

	df	SS	MS	*F*	*p*
Gear	4	59020	14755	75.69	<0.0001
Sex	1	3686	3686	18.91	<0.0001
*Gear * Sex*	4	2287	572	2.93	0.0195
Error	9629	1877107	195		
Total	9638	1945710			

Table 4.3. Summary of lobster catches and carapace length (mm) per fishing gear obtained in 2020, 2021 and 2022: Mean soak days and catch per unit effort (CPUE, lobsters/day/gear); Lobster length at first capture (L_C); the length when lobsters become vulnerable to fishing gear (L_X); length of the first frequency mode when lobsters all individuals are vulnerable and captured by a specific gear (L_p); mean length of catch (L_m); length of the largest 5% individuals (L_{95}) and maximum length (L_{max}). SE is standard error.

Fishing Gear		Catch					Length								
Type	**Escape vents**	**Strings**	**Soak days**	SE	**CPUE**	SE	**N**	**L_X**	**L_C**	**L_p**	**N_m**	**L_m**	SE	**L_{95}**	**L_{max}**
Multi-pots	Y	10	6.8	±0.2	0.7	±0.1	563	48	71	80	469	85.3	0.5	103	120
	N	220	5.0	±0.2	1.2	±0.1	3905	36	61	80	3419	80.5	0.2	103	146
Pots	Y	60	6.1	±0.1	0.1	±0.01	342	65	79	82	322	88.6	0.5	105	120
	N	484	3.7	±0.1	0.7	±0.03	1925	40	67	76	1634	87.3	0.3	111	134
Fyke Net (Eel)	Y	20	6.3	±0.1	0.4	±0.04	495	44	67	82	440	80.6	0.4	96	126
	N	58	7.3	±0.6	0.4	±0.04	681	44	63	78	631	80.8	0.4	99	152
Fyke Net (Cod)	Y	16	8.4	±0.5	1.0	±0.1	287	57	75	80	233	84.3	0.5	97	112
	N	4	9		0.4	±0.1	885	54	78	82	682	84.9	0.2	95	127
Nets	N	85	6.4	±0.5	0.5	±0.1	561	41	59	64	510	84.6	0.6	107	134

L_X in gear with no escape vents ranged between 36 mm in multi-pots and 54 mm in cod fyke nets, with intermediate values of 40 mm in pots, 41 mm in nets and 44 mm in eel fyke nets (Table 4.3). Escape vents only had a clear impact on L_X in multi-pots and pots, resulting in increases of 12 and 25 mm (Table 4.3). In eel and cod fyke nets, escape vents resulted in an increase of L_X of 0 and 3 mm, respectively (Table 4.3).

L_C in gear without escape vents ranged between 59 mm in nets and 78 mm in cod fyke nets, with intermediate values in multi-pots of 61 mm, eel fyke nets of 63 mm and pots of 67 mm (Table 4.3 and Figure 4.4). L_C increased in gear with escape vents, by 3, 4, 10 and 12 mm in cod fyke nets, eel fyke nets, multi-pots, pots, respectively (Table 4.3 and Figure 4.4).

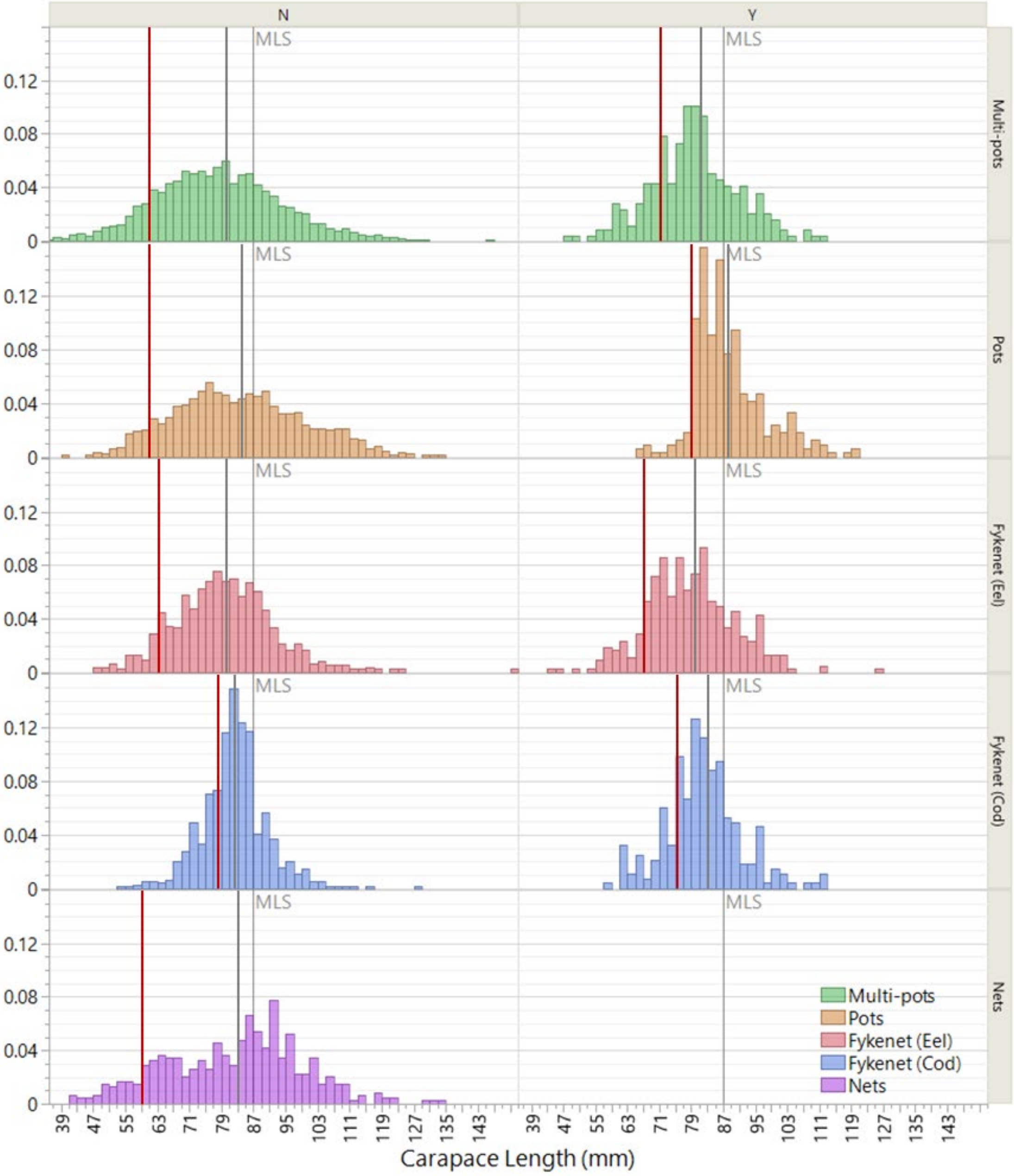

Figure 4.4. Frequency distribution (%) of carapace length (mm) in 2 mm classes per fishing gear obtained in 2020, 2021 and 2022. Red line is length at first capture (L_C) and black line is mean length of catch (L_m). Grey line is minimum landing size (MLS).

L_m on gear with no escape vents differed by up to 6.5 mm, being highest in pots at 87 mm and lowest in multi-pots and eel fyke nets at 81 mm, with intermediate values in cod fyke nets and nets of 85 mm (Table 4.3 and Figure 4.4). L_m differed significantly between gear type with no escape vents (non-parametric Kruskal-Wallis, H = 347.5, $p < 0.0001$), being longer in pots and cod fyke nets, and shorter in multi-pots and eel fyke nets (Dunn test, $p < 0.0001$ for all, except pots and nets at $p = 0.016$). L_m were not different in pots and cod fyke nets, in cod fyke nets and in nets, and in multi-pots and eel fyke nets (Dunn test, $p > 0.05$ for all).

When escape vents were used, L_m increased by 4.8 mm in multi-pots and 1.3 mm in pots, while in both types of fyke nets it decreased by 0.2 and 0.6 mm (Table 4.3 and Figure 4.4). L_m differed significantly between gear with escape vents (non-parametric Kruskal-Wallis, H = 164.7, $p < 0.0001$), being longer in pots than other gear types (Dunn test, $p < 0.0001$, except pots and cod fyke nets at $p = 0.006$) and shorter in eel fyke nets than in multi-pots and cod fyke nets (Dunn test, $p < 0.0001$), but similar in multi-pots and cod fyke nets (Dunn test, $p > 0.05$).

The longest lobster (L_{max}) was 152 mm captured with eel fyke nets, while L_{95} ranged between 95 and 111 mm (Table 4.3).

Table 4.4. Summary of lobster length (mm) data during summer-autumn 2021 in a protected area with no fishing, Livø MPA, and three fished areas, Ejerslev Røn–Mors/Fegge, Fur West, and Kås Syd (Figure 4.1). Lobster pots we used in Livø MPA, a mix of multi-pots (%) and eel fyke nets (%) in Fur west and multi-pots in Ejerslev Røn–Mors/Fegge and Kås Syd, and none of the gear had escape vents. A common LC of 67 mm was used. Mean length of catch (L_m) and length of the largest 5% (L_{95}) from the fraction larger than a L_C. Maximum length in the catch (L_{max}). *J'* is the evenness in distribution among size classes larger than L_C. L_{50L} and L_{mL} are length when 50% of landings were obtained and mean length of landings, respectively. In italics low sample size (<100). Significant differences (non-parametric Kruskal-Wallis test) are indicated by * at $p < 0.001$, ** at $p < 0.05$, ns is non-significant at $p > 0.05$.

		Catch								Landings				
Location		**L_C**	**N_{total}**	**N_m**	**L_m**	SE	**L_{95}**	**L_{max}**	***J'***	**N_L**	**%**	**L_{50L}**	**L_{mL}**	SE
Protected														
Livø MPA		67	643	601	93.2*	0.6	115		0.969	362	56.3	102	102.2*	0.5
	F		211	192	87.4*	0.8	106	117		*73*	*34.6*	*95*	*96.3*	*0.8*
	M		430	407	95.9*	0.7	117	126		289	67.2	104	103.6*	0.5
Fished														
Ejerslev/Mors		67	862	667	81.4**	0.4	102		0.908	154	17.9	93	95.4^{ns}	0.6
	F		270	241	79.3^{ns}	0.6	100	118		*22*	8.1	*98*	*97.4*	*1.6*
	M		592	426	82.6** ^{ns}	0.5	102	122		132	22.3	93	95.1^{ns}	0.7
Fur W		67	678	616	82.9*	0.4	100		0.913	160	23.6	92	94.9^{ns}	0.6
	F		301	273	80.9*	0.5	97	116		*34*	11.3	*93*	*95.7*	*1.4*
	M		377	343	84.5** *	0.5	100	123		126	33.4	92	94.7^{ns}	0.7
Kås Syd		67	460	429	78.9*	0.4	96		0.936	*39*	*8.5*	*90*	*92.3^{ns}*	*0.8*
	F		254	217	77.7*	0.6	96	115		*6*	*2.4*	*96*	*100.5*	*4.7*
	M		206	212	80.2^{ns} *	0.6	92	110		*33*	16.0	*90*	*91.0^{ns}*	*0.9*

Protected and fished areas

Since different fishing gear were used in each area – pots in Livø MPA, multi-pots in Ejerslev Røn–Mors/Fegge and Kås Syd, and a mix of multi-pots (ca. 50%) and eel fyke nets (ca. 50%) in Fur W – the longest L_C was used, i.e. the one of pots (Table 4.1) to attempt to minimize the impact of gear selectivity on SBIs and allow a comparison between areas.

Data is presented separately for female and male lobsters, however statistical analysis of the landed fraction was not done for females due to low sample size (Table 4.4).

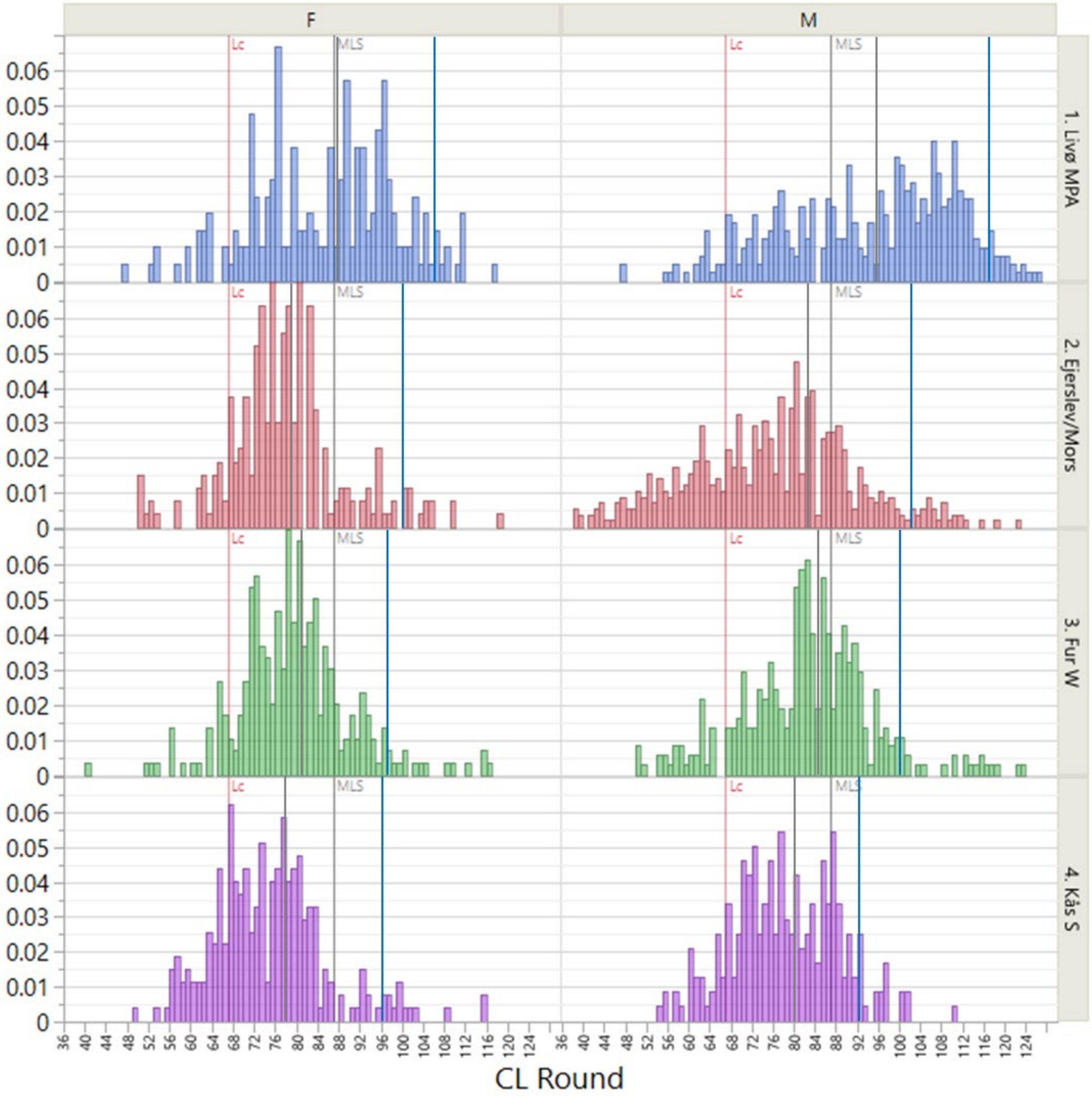

Figure 4.5. Frequency distribution (%) of carapace length (mm) in a protected area, with no fishing, Livø MPA (top), and three fished areas, Ejerlev Røn–Mors/Fegge, Fur West, and Kås Syd (bottom). Red line is length at first capture (L_C), black line is mean length of catches (L_m, black line), and blue line is length of the largest 5% individuals (L_{95}). Grey line is minimum landing size (MLS). F – females and M – males.

L_m was only larger than MLS in the protected Livø MPA, both in female and male lobsters (Table 4.4 and Figure 4.5). L_m was significantly different in the four locations both for female and male lobsters (non-parametric Kruskal-Wallis, $H = 92.6$ and 244.5, $p < 0.0001$ for both), being longer in the protected Livø MPA than in the three fished areas by 6.5 to 9.7 mm in females and by 11.3 to 15.7 mm for males (Table 4.4 and Figure 4.5; Dunn test, $p < 0.0001$ for all).

In the three fished areas, L_m was longer in Fur W and shorter in Kås Syd (Table 4.4 and Figure 4.5; Dunn test, $p < 0.0012$ for all), except between males in Fur W and Ejerslev/Mors (Dunn test, $p = 0.039$). L_m was not different between females in Fur W and Ejerslev/Mors, in Kås Syd and Ejerslev/Mors and between males in Kås Syd and Ejerslev/Mors (Table 4.4 and Figure 4.5; Dunn test, $p > 0.05$ for all).

L_{95}, quantifying the abundance of the largest individuals, was longest in the protected Livø MPA at 115 mm CL than in the three fished areas, which had shorter L_{95} values shorter between 102 and 96 mm (Table 4.4 and Figure 4.5). The same pattern also occurred in either female or male lobsters (Table 4.4).

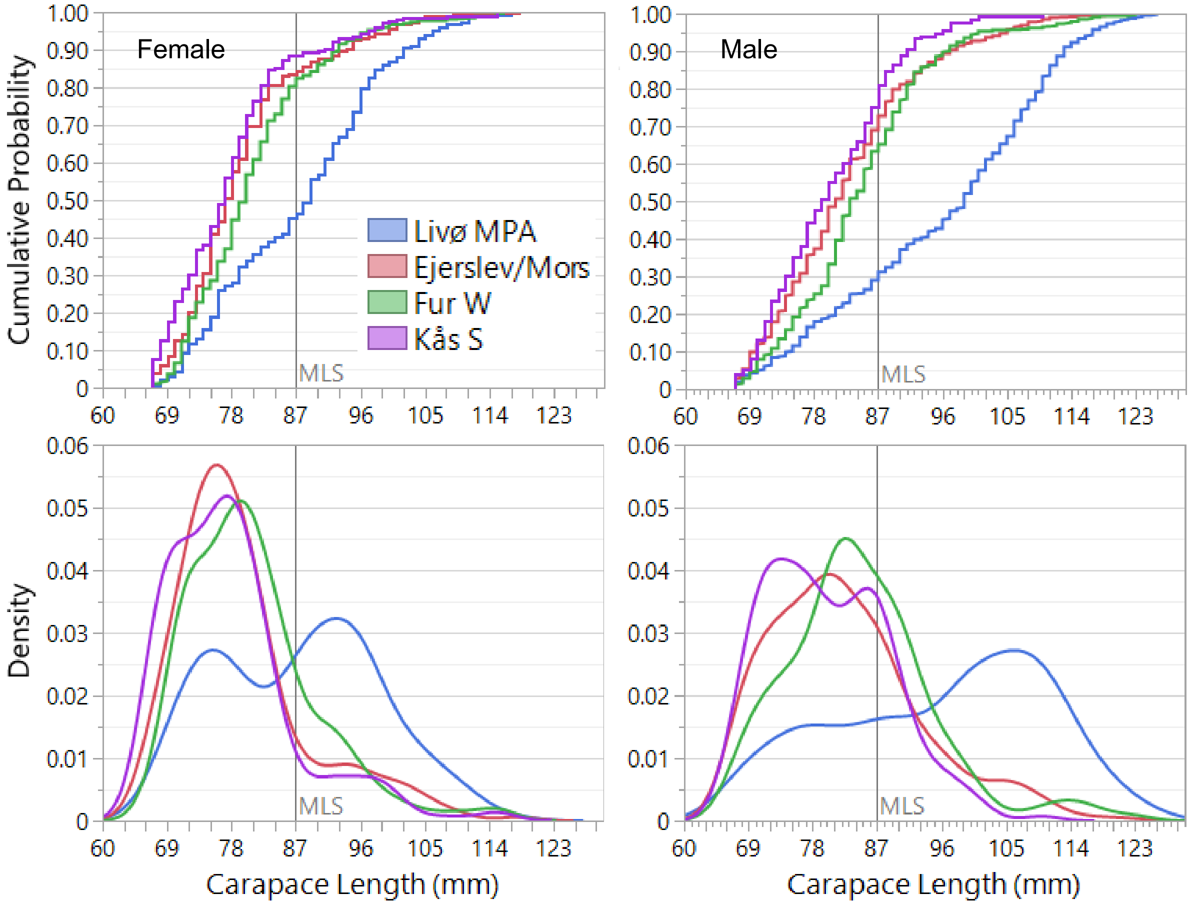

Figure 4.6. Cumulative distribution functions (top) and Kernel density estimation (bottom), to visualise the contribution of each level of carapace length. Female (left) and male (right) lobsters larger than length at first capture (L_C) in a protected area, with no fishing, Livø MPA, and three fished areas, Ejerlev Røn–Mors/Fegge, Fur West, and Kås Syd. MLS is minimum landing size (grey line).

Length-frequency distributions were different between the protected Livø MPA and the fished areas both for female and male lobsters (Figure 4.6; Kolmogorov-Smirnov test, $D > 0.36$, $p < 0.001$), and also between fished areas (Figure 4.6; Kolmogorov-Smirnov test, $D > 0.14$, $p < 0.017$) except between Ejerslev/Mors and Kås Syd (Figure 4.6; Kolmogorov-Smirnov test, $D < 0.12$, $p > 0.05$).

While in fished areas, small size classes contributed most of the abundance, reaching between 64 to 89 % at MLS (Figure 4.6). In the protected Livø MPA, larger size classes accounted for most of the abundance, with lengths shorter than MLS contributing only 30 and 46 % in female and male lobsters, respectively, confirming that lobsters in the protected area reached and were more abundant at larger sizes than in fished areas, particularly for males (Figure 4.6).

The protected Livø MPA had the highest evenness in the distribution among size classes, followed by Kås Syd, but with a smaller range of carapace length, with and Fur W having the lowest evenness in size distribution (Table 4.4).

Considering the landed fraction only, i.e. larger or equal to 87 mm CL and excluding ovigerous females, L_{mL} was longer in the protected Livø MPA than in the fished areas (Table 4.4; Kruskal-Wallis, *H* = 125.6, *p* < 0.0001; Dunn test, *p* < 0.0001 for all), while fished areas did not differ between each other (Table 4.4; Dunn test, *p* > 0.174 for all). L_{mL} in fished areas ranged between 92.5 and 95.4 mm, only 5.5 to 7.4 mm longer than MLS, while in the protected Livø MPA L_{mL} was 102.2 mm, 15.2 mm longer than MLS.

For male lobsters only, since sample size of female lobsters was low, L_{mL} was longer in the protected Livø MPA than in the fished areas (Table 4.4; Kruskal-Wallis, *H* = 147.1, *p* < 0.0001; Dunn test, *p* < 0.0001 for all), while fished areas did not differ between each other (Table 4.4; Dunn test, *p* > 0.067 for all)

L_{50L}, the length at which 50% of landings would be obtained, was 102 mm CL in the protected Livø MPA, while in the fished areas it ranged between 90 to 93mm CL and thus only 3 to 6 mm longer than the MLS of 87 mm CL (Table 4.4).

Lobster size in spring 2022

Table 4.5 presents a detailed summery of SBIs obtained in 5 broad areas of the Limfjorden in spring 2022. Since different fishing gear were used in each area (Table 4.5), including some with escape vents, the longest L_C was used to filter all data, i.e. the one of pots with escape vents (Table 4.1) to attempt to minimize the impact of gear selectivity on SBIs and allow comparison between areas (Figure 4.7).

CL was different according to sex in Kås Bredning, Venø Sund and Nissum Bredning (non-parametric Kruskal-Wallis, *H* = 5.80 to 22.04, *p* = 0.0001 to 0.016), with longer males than females, except in Nissum Bredning where males were longer than females (Table 4.5).

L_m of both female and male lobsters differed between areas (Kruskal-Wallis, *H* = 117.44 and 31.08, *p* < 0.0001 for both). L_m of both female and male lobsters was longest in Løgstør–Livø and shortest in Kås Bredning (Table 4.5 and Figure 4.7).

L_{95} of female lobsters was longest in Nissum Bredning at 110 mm and shortest at Kås Bredning and Venø Sund at 94 and 95 mm, respectively (Table 4.5). L_{95} of male lobsters was longest in Løgstør–Livø at 104 mm, and shortest at Sønder–Salling and Kås Bredning at 96 and 97 mm, respectively (Table 4.5 and Figure 4.7).

Considering the landed fraction, only 28% of all lobsters caught, 26 % of females and 31% of males, constituted landings (Table 4.5). L_{50L} ranged only by 4 mm between 89 mm for female lobsters and 93 mm for male lobsters, both in Venø Sund (Table 4.5 and Figure 4.7).

Aggregating all areas, L_{50L} of both female and male lobsters in spring 2022 was 92 mm, only 5 mm longer than MLS. While mean CL of landings, L_{mL}, was 95 and 94 mm, respectively, corresponding to ca. 62% of landed females and males (Table 4.5 and Figure 4.8).

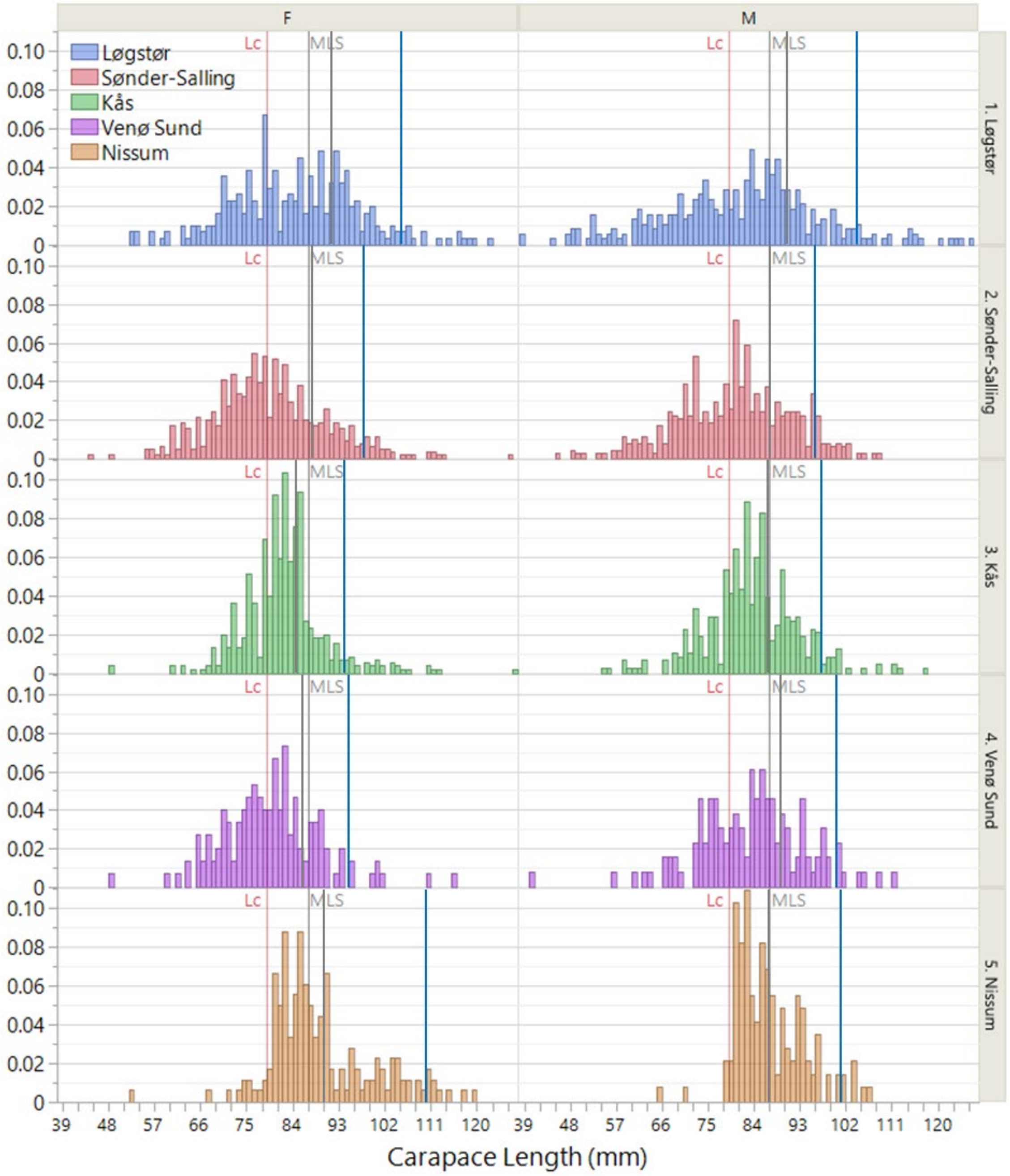

Figure 4.7. Frequency distribution (%) of carapace length (mm) from several basins in the Limfjorden during Spring 2022 (Figure 4.1). Red line is length at first capture (L_C), defined as the same for all gear as the longest L_C of all the types of gear used (pots), black line is mean length of catches (L_m), and blue line is length of the largest 5% individuals (L_{95}). Grey line is minimum landing size (MLS). F – females and M – males.

Table 4.5. Summary of length data from several basins in the Limfjorden during Spring 2022 (Figure 4.1). Lobster length at first capture (L_C), mean length of catch (L_m), Length of the largest 5% (L_{95}) and maximum length (L_{max}), length when 50% of landings are obtained (L_{50L}) and mean length of landings (L_{mL}). MP – Multi-pots, P – Pots, EF – Eel fyke nets and CF – Cod fyke nets. A L_C was used equal to the longest of all gear, pots with escape vents. In italics low sample size in landed fraction (< 100). SE is standard error.

	Type of Gear (%)				Catch							Landings				
Basin	**MP**	**P**	**EF**	**CF**	**N**	**L_C**	**N_m**	**L_m**	SE	**L_{95}**	**L_{max}**	**N_L**	**%**	**L_{50L}**	**L_{mL}**	SE
Løgstør-Livø	100				708	79	432	90.8	0.4	105		190	26.8	92	94.8	0.6
F					315		201	91.2	0.6	105	122	*52*	*16.5*	*92*	*92.8*	*0.9*
M					392		230	90.5	0.6	104	126	138	35.2	92	95.6	0.8
Sønder-Salling	39	1	60		1216	79	632	87.4	0.3	97		216	17.8	92	93.2	0.3
F					669		316	87.7	0.4	98	126	*69*	*10.3*	*92*	*93.5*	*0.8*
M					550		316	87.2	0.4	96	108	147	26.7	92	93.1	0.4
Kås Bredning		14		86	1103	79	797	85.7	0.2	96		214	19.4	91	92.6	0.4
F					613		432	84.9	0.3	94	127	69	11.3	90	92.0	0.8
M					489		365	86.7	0.3	97	117	145	29.7	91	92.9	0.4
Venø Sund		25	35	40	285	79	170	87.6	0.6	100		*71*	*24.9*	*91*	*93.5*	*0.9*
F					152		80	85.9	0.8	95	115	*24*	*15.8*	*89*	*91.3*	*1.3*
M					133		90	89.0	0.9	100	134	*47*	*35.3*	*93*	*94.6*	*1.2*
Nissum Bredning		100			332	79	315	88.7	0.5	105		115	34.6	92	93.6	0.6
F					183		171	89.9	0.7	110	119	*54*	*29.5*	*90*	*93.7*	*1.0*
M					147		142	87.0	0.5	101	106	*60*	*40.8*	*92*	*93.1*	*0.6*
Total					3647		2346	87.7	0.2			1037	28.4	92	94.2	0.2
F					1932		1200	87.5	0.2			499	25.8	92	94.6	0.3
M					1711		1143	87.8	0.2			537	31.4	92	93.8	0.3

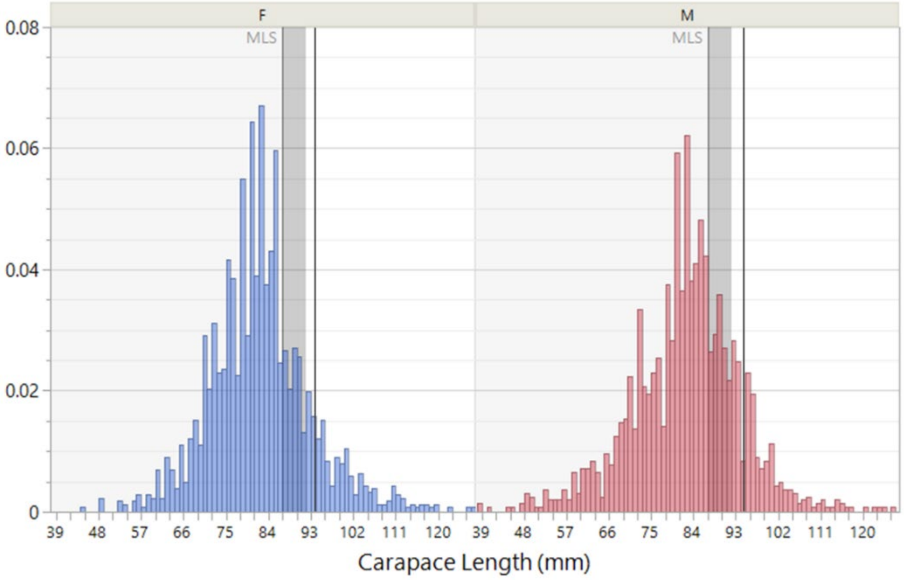

Figure 4.8. Frequency distribution (%) of carapace length (mm) in the Limfjorden during Spring 2022 (Figures 4.1 and 4.5). Light grey shading are undersized lobsters smaller than MLS; dark grey shading is the length when 50% of landings were obtained (L_{50L}); black line is mean length of landings (L_{mL}). F – females and M – males.

Growth of juvenile cohort 2020-2022

The growth of a juvenile cohort was followed from catch data since the summer/autumn 2022 until spring 2022, and for males until autumn 2022, when it began to recruit into the fishery (Table 4.6 and Figure 4.9).

Table 4.6. Growth of a lobster juvenile cohort in the Limfjorden from summer/autumn 2020 to autumn 2022. Carapace length (CL, mm) data from catches with multiple types of fishing gear. Growth (mm) is the increase in mode CL between consecutive seasons. Areas: LMF – Limfjorden, L – Løgstør/Livø, S/S – Sønder/Salling, K – Kås Bredning, VS – Venø Sund, VB – Venø Bugt, N – Nissum Bredning. Note: * Low sample size or limited spatial coverage.

		Female			Male		
Year – Season	**Areas**	N	Mode CL	Growth mm	N	Mode CL	Growth mm
2020							
*Summer/Autumn	LMF, L	179	60		256	60	
2021							
Spring	L, K, VS	1207	66	6	1370	66	6
*Summer	L	290	76	10	562	78	12
Autumn	L, S/S, K	898	78	2	1269	80	2
2022							
Spring	L, S/S, K, VB, VS	1981	82	4	1775	82	2
*Autumn	L	51	*	*	111	>88	>6

Growth was observed both between spring and autumn and also between autumn and the following spring, ranging from 2 to 6 mm in the former and from 12 to 14 mm in the latter, corresponding to an annual growth (spring to spring) of 16 mm CL (Table 4.6 and Figure 4.9).

The juvenile cohort grew from a mode of 60 mm CL in summer/autumn 2022 to 82 mm CL by spring 2022 in both female and male lobsters (Table 4.6 and Figure 4.9). The male lobster cohort mode reached >88 mm CL by autumn 2022 (Table 4.6 and Figure 4.9).

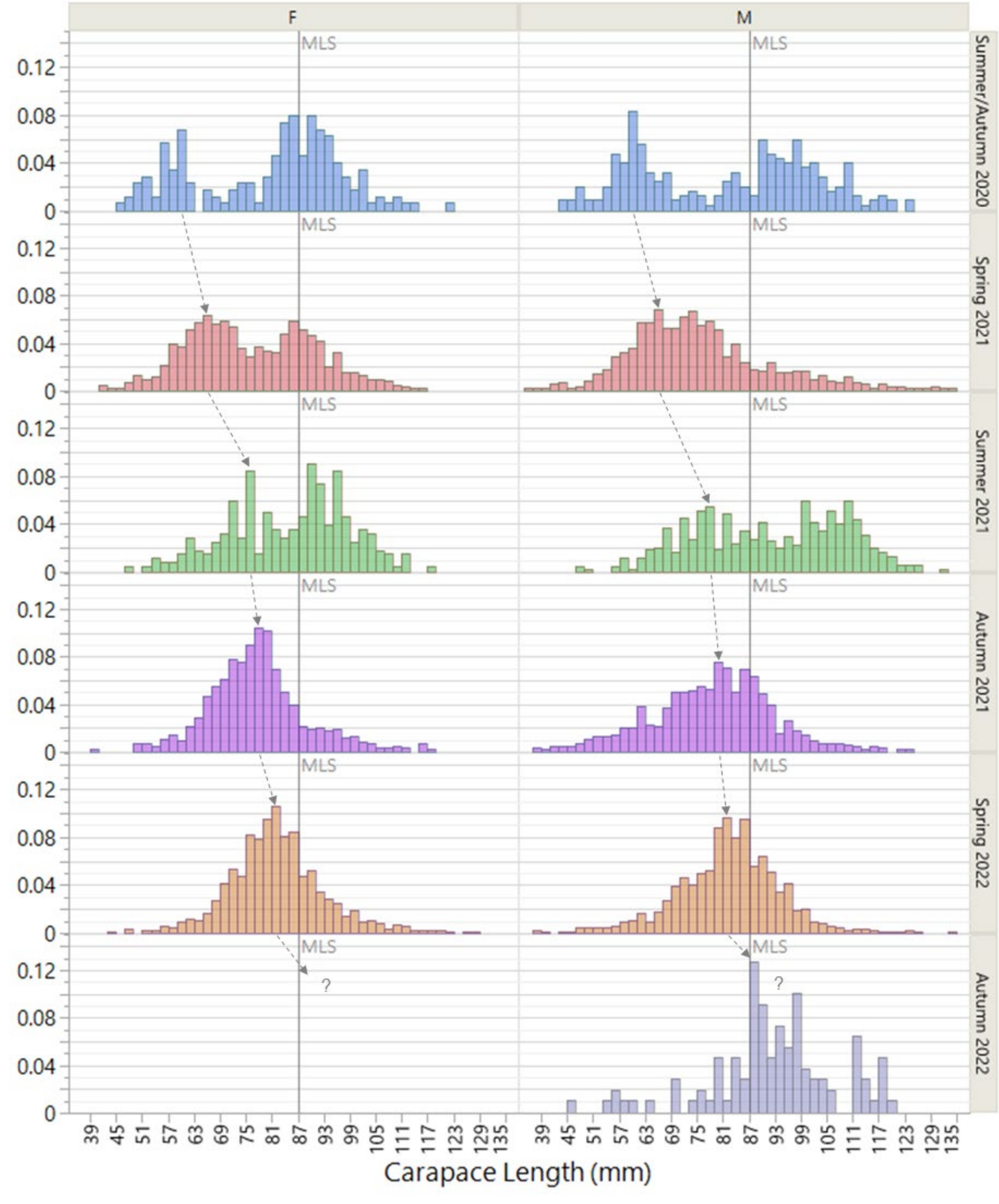

Figure 4.9. Growth of a lobster juvenile cohort in the Limfjorden from summer/autumn 2020 to autumn 2022 (Table 4.4). Carapace length (mm) data from catches with multiple types of fishing gear. Summer 2021 includes catches from a protected non-fished area that explain abundance of larger sizes.

4.4 Conclusions

The objective of this task was to obtain information on the size structure of the Limfjorden lobster population that has been fished since the early 2000's. To that purpose, carapace length data was obtained, often opportunistically, from the recreational and commercial fishery, as well as two independent surveys, from spring of 2020 to autumn of 2022. The data comes from a heterogenous mix of fishing gear, setup, locations and time, and therefore presents limitations, but provides a first insight into lobster size in the Limfjorden.

Allometric relationships specific to the Limfjorden population were obtained that easily permit to convert carapace length, total length and weight measurements (Figures 4.2 and 4.3). As a reference a lobster with minimum landing size of 87 mm CL, would have a TL of 240 mm and a weight of 500 g if female or 550 g if male. At L_{mL}, mean length of landings, female lobsters have 93.6 mm CL, a TL of 260 mm and a weight of 604 g, while male lobsters will have 94.8 mm CL, a TL of 260 mm and a weight of 722 g.

Differences in size and sex selectivity of different fishing gear were observed (Figure 4.4), with L_m being longer in pots that most other gear and males being longer than females. However, since data did not originate from standardized trials under the same conditions, but rather from different fishing grounds, at different times and with different set ups (mesh size, escape vent size, design), such results must be considered with caution.

As usual in fished populations (e.g., Gendron and Savard 2003), the Limfjorden lobster populations show a significantly compressed size structure with truncated size distributions and a reduction in the abundance of larger sizes (Figures 4.5 and 4.6). A comparison between lobsters in a protected area with no fishing, albeit still under some fishing mortality (Petersen et al., 2022), with three fished areas showed significantly larger sizes in the protected area (Figures 4.5 and 4.6). Only in the protected area was L_m longer than MLS, with fished areas having shorter L_m than the protected area by 7 to 10 mm in females and 11 to 16 mm in males. In the protected area, 56% of the catch was in the landed fraction while in the fished areas only between 9% to 24%.

An assessment of the current lobster size structure in the Limfjorden in spring 2022 was obtained from five basins, ranging from Nissum Bredning in the west to Løgstør Bredning in the northeast, which confirmed a significantly compressed size structure with truncated size distributions (Figures 4.7 and 4.8). The size at which 50% of landings were obtained (L_{50L}) was only 5 mm longer than the MLS of 87 mm CL (Figure 4.8), corresponding at most to half or one moult increment after MLS (Hepper, 1967; Agnalt et al., 2007; Wahle et al., 2013 and references therein). L_{mL} was only 7 mm longer than MLS (Figure 4.8), at most one or two moult increments after MLS (Hepper, 1967; Agnalt et al., 2007; Wahle et al., 2013 and references therein).

Determining the age and growth of *Homarus* lobsters, as in many crustaceans, remains complex and often uncertain (e.g. Sheehy et al., 1996, 1999; Uglem et al., 2005) and thus together with the highly variable growth rate of lobsters, it is usually not possible to perform modal analysis to follow the evolution of individual size classes or cohorts in a lobster population (e.g. Tully et al., 2006). However, on occasions that has been achieved for juveniles of the American lobster, *Homarus americanus* (Wahle et al., 2013 and references therein). We were able to infer the seasonal and annual growth increments by modal analysis of the size distribution of a clear juvenile size class in the Limfjorden, assumed to represent a single age cohort (Figure 4.9).

The juvenile cohort was first observed in summer/autumn 2020 at 60 mm CL and was followed until spring/autumn 2022. Growth occurred between spring and autumn and also between autumn and the following spring, with growth being lower in the latter period. Seasonal growth increments varied between 2 to 6 mm from autumn to spring and 12 to 14 mm from spring to autumn, with annual increments of 16 mm CL (spring to spring).

These observations indicate moulting occurs at different times of the year, not just in late spring and summer. The moulting frequency and growth increment observed at lengths just shorter than MLS (i.e. 76–>88 mm) indicate a significant fraction of the cohort underwent moulting at least once a year, while at smaller lengths (i.e. 66–82 mm) double moulting in a year must occur to account for 16 mm in growth over one year (i.e. spring 2021 to spring 2022, Table 4.6). Thus, in the Limfjorden female lobsters to MLS follow a one-year reproductive cycle and not a 2-year reproductive cycle (Chapter 5, this report).

It took approximately two years for lobsters of 60 mm CL to grow to the MLS of 87 mm CL (Figure 4.9). Considering histological ageing (Uglem et al., 2005) and mark-recapture observations in the North Sea (Schmalenbach et al., 2011), European lobsters of 60 mm CL most likely have an age of three or four years. Thus, it should take five or six years for lobsters to reach MLS in the Limfjorden, compared with four to five years to reach 85 mm CL on the east coast of the UK (Bannister et al., 1994).

The juvenile cohort started to recruit in spring 2022, when the largest sizes of the cohort grew larger than MLS, with most recruiting by autumn 2022 for male lobsters. However, due to the small sample size in autumn 2022 and the recruitment into the fishery, the size of the modal class is most likely underestimated.

The Limfjorden lobster population shows a significantly truncated size distribution and is dependent on newly recruited individuals to at least sustain a significant proportion of current commercial landings. The recruitment of this juvenile cohort explaining the exceptional landings obtained in 2022 of >40 tons, almost double 2021 and 67% above mean annual landings since 2015. In particular, it explains the record landings obtained during autumn of 2022 in all months from September to December (Chapter 3, this report).

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5. European lobster (*Homarus gammarus*) maturity and reproductive potential in the Limfjorden

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5.1 Rationale

Establishing the reproductive biology of an exploited species is essential for the correct assessment and management of a stock's sustainability (e.g. Caddy and Defeo, 2003; Whale et al. 2020). Size at maturity and variations in reproductive potential with size and age are essential to define a level of fishing that maintains sufficient spawning capacity and egg production (e.g. ICES 2003; Hoggarth et al., 2009).

For lobster and other crustacean fisheries, ensuring good egg production was recognized as the most important parameter for sustainable management, with egg-per-recruit models being used on both sides of the Atlantic in fisheries of the two clawed lobsters, the American lobster *Homarus americanus* and the European lobster *Homarus gammarus*, (ICES, 2003). In homarid lobsters as in many other animals, fecundity (i.e. the number of eggs produced) increases as a cube of body length, which together with its long life span and low natural mortality means that large female lobsters have a significantly larger reproductive potential and produce significantly more eggs than several smaller females (Tully et al., 2001; Tully, 2004; Agnalt, 2008).

The only common technical management measures in homarid lobster fisheries to ensure egg production and preserve reproductive potential, are minimum landing sizes (MLS), and less frequently but increasingly the protection of egg bearing (ovigerous) females (ICES, 2003; Woolmer et al., 2013; ICES 2021). In European lobster fisheries, MLS was set at 87 mm carapace length (CL) at European level as a technical conservation measure (EU Regulation 2019/1241; with the exception of the Mediterranean Sea at 105 mm, the Skagerrak and Kattegat at 78 mm), with some countries and regions imposing larger MLS, e.g. Norway, Sweden, regions of UK, France (ICES, 2003, 2021; Woolmer et al., 2013).

The size at first maturity ($CL_{50\%}$), defined as the average size at which 50% of female lobsters have reached sexual maturity, is an important life history and reproductive trait, and is considered the relevant reference point to establish minimum legal sizes of landings that aim to avoid landing functionally immature individuals (e.g. Tully et al. 2001, Tully 2004; Tully 2006; Wood, 2018). If the size or age at first capture/landing is smaller than the size or age at first maturity there is a risk of recruitment overfishing where recruitment to the exploitable stock becomes significantly reduced (e.g. Caddy and Mahon, 1995).

Commonly, a logistic model is used to describe the relationship between body size and sexual maturity and estimate $CL_{50\%}$ from the proportion of mature females in each size class. However, maturity in lobsters has been defined in multiple ways (Aiken and Waddy, 1980; Tully et al., 2001; ICES, 2003; Laurans et al., 2009): as physiological maturity (i.e. when a lobster starts to produce spermatozoa or ovules), as morphological maturity (i.e. when lobsters can copulate and spawn effectively), and functional maturity (i.e. when females are able to extrude eggs and become ovigerous). For fishery purposes, functional maturity based on the size at which females will extrude eggs is needed (ICES, 2003) and is the most relevant parameter to model fecundity of a stock, reproductive potential or egg yield-per-recruit (e.g. Tully et al., 2001; Agnalt et al., 2007; Laurans et al., 2009).

Several methods are used to assess lobster physiological and morphological maturity, but however their assessment is either time consuming and unpractical for the former (e.g. collection of pleopods or dissection of ovaries) or unreliable for the latter (Tully et al., 2001, ICES, 2003). Functional maturity in lobsters can be easily determined from observation of ovigerous state (presence/absence of eggs under the abdomen) of female lobsters (ICES, 2003). Nevertheless, ovigerous-based functional maturity is affected by sample size, and annual and seasonal variations (e.g. Tully et al., 2001; Laurans et al., 2009) and should only include data from periods prior to spawning but after egg extrusion, thus excluding summer, fall and winter (ICES, 2003).

The reproductive cycle of European lobsters is still not fully understood with significant variation and descriptions of both an annual cycle (e.g. Latrouite et al., 1981, 1984; Tully et al., 2001; Laurans et al., 2009; Wood, 2018) and a biennial cycle with alternating reproduction and moulting (e.g. Tully et al., 2001; Agnalt et al., 2007). However, the occurrence of a biennial cycle over the entire European lobster geographical distribution and at all sizes is far from certain. Determining the occurrence of annual or biennial cycle is fundamental as it significantly affects size-at-maturity estimations.

While the relationship between size and fecundity in the European lobster is not expected to vary significantly geographically (Tully et al., 2001), although a recent study reported a positive correlation with easterly longitude and annual range of water temperature (Ellis et al., 2015), large differences in $CL_{50\%}$ have been described (e.g. Tully et al., 2001, Lizarraga-Cubedo et al., 2003; ICES, 2003; Laurans et al., 2009; ICES, 2021; SIFCA, 2021) and thus require $CL_{50\%}$ to be determined for each stock.

Regulatory measures in the Limfjorden lobster fishery, and the rest of Denmark as well, such as minimum landing size, protection of berried females and closed period, although important and valid measures, were implemented with no studies having been conducted on European lobster reproductive cycle, fecundity, maturity, and egg production.

This study determined the size at onset of maturity for the lobster population in the Limfjorden from female ovigerous state in the spring fishing season. In addition, the reproductive potential of female lobsters was estimated in several fishing grounds in the Limfjorden and compared to a protected area to assess the impact of fishing on reproductive potential. The findings represent the first estimates of maturity and reproductive potential for the Limfjorden (together with a parallel project), important for the future management of the fishery by assessing the protection of egg production capacity provided by the current minimum landing size and the protection of berried females.

5.2 Methods

Catch data

Size and female ovigerous state data were obtained from catches in both the commercial and recreational fisheries and from fishery independent surveys in 2020, 2021 and 2022.

Catch reports were provided by recreational fishermen taking part in a voluntary report program (Nøglefiskere) in the fishing grounds off northern Morsø and Ejerslev Røn during the spring and autumn fishing seasons of 2020, 2021 and 2022 (black dots in Figure 5.1).

On-board observers catch data from the commercial fishery was obtained in four fishing grounds in the 2021 autumn fishing season and 15 fishing grounds in the 2022 spring fishing season covering most of the main fishing grounds in different basins of the western and central Limfjorden (Figure 5.1).

Catch data from two research surveys was obtained outside the fishing seasons in the summers of 2020 and 2021 (Petersen et al., 2022), the former across most of the western and central Limfjorden and the latter only in the Livø stone reefs marine protected area (Figure 5.1).

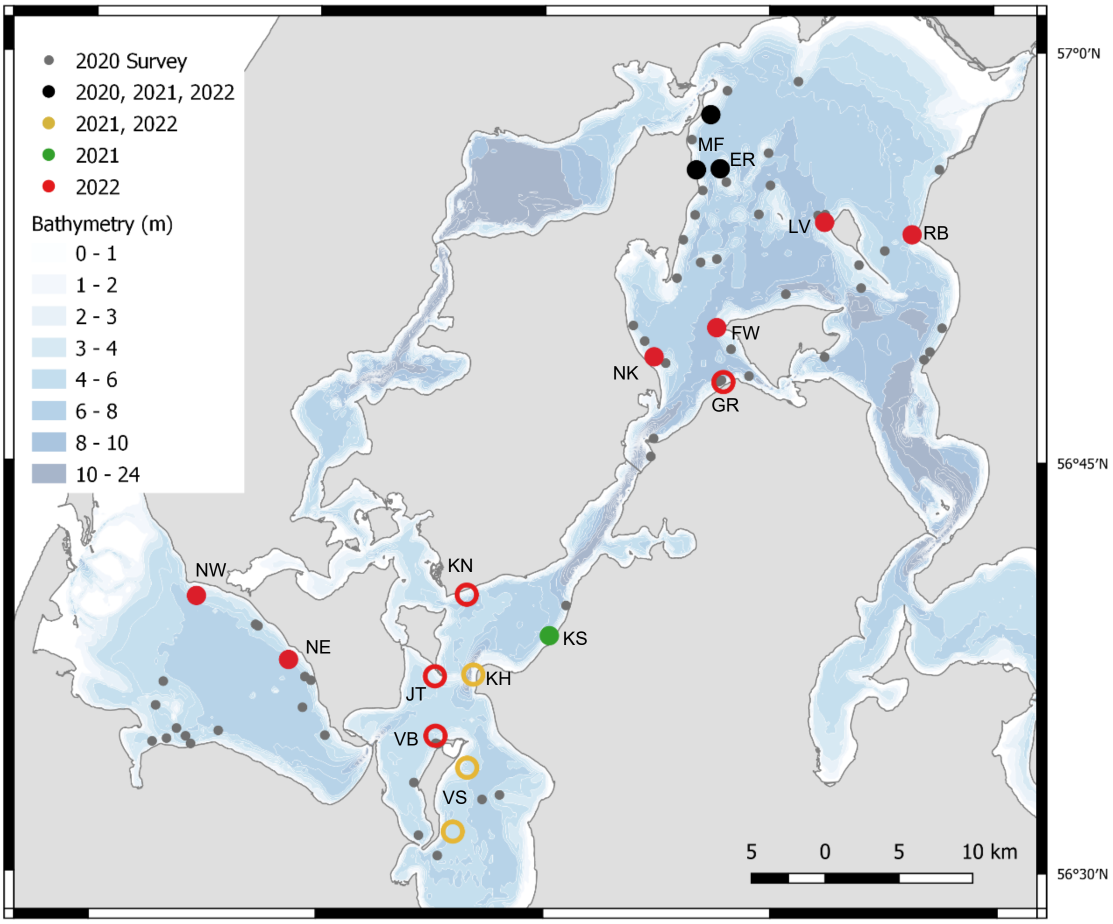

Figure 5.1. Location of fishing grounds and years with catch data: from recreational fishermen (black dots) for 2020, 2021 and 2022 provided catch data; from observer reports in the commercial fishery (yellow, green and red dots) for 2021 and 2022; and research surveys (grey dots) for 2020. Maturity data are only from springs. Open circles are data from 2022 excluded from maturity analysis since sampling likely occurred post-hatching. Fishing grounds referred to in the text and Table 5.1: Mors/Fegge – MF; Ejerslev Røn – ER; Livø – LV; Rønbjerg – RB; Fur W – FW; Grynderup – GR; Nykøbing – NK; Kås Syd – KS; Kås N – KN; Kås Hoved – KH; Jegind Tap – JT; Venø Bugt – VB; Venø Sund – VS; Nissum West – NW; Nissum East – NE.

Fisheries-based catch data was obtained from different types of gear allowed in the Limfjorden lobster fishery ranging from lobster pots, multi-pots (aka. Kinaruser), gill and trammel nets, and fyke nets.

Survey catch data was obtained from lobster pots. Although variations are to be expected over different gear, for the purposes of this study catchability of non-ovigerous and ovigerous female lobsters and size selectivity are assumed to be the same and unaffected by the type of fishing gear.

Carapace length (CL) was measured to the nearest mm from the back of the eye socket to the posterior edge of the cephalothorax. Lobsters were sexed based on morphological differences in the first pair of pleopods/swimmerets and the egg bearing status (ovigerous) of females determined.

Size distribution of landings were compiled from all data and for all years and seasons by removing catches smaller than the 87 mm MLS and ovigerous females (berried).

Table 5.1. Summary statistics of female lobster ovigerous status and carapace length (mm) obtained in the Limfjorden in the springs of 2020, 2021 and 2022. * Indicates fishing grounds sampled in 2022 that were excluded from analysis due to low prevalence of ovigerous females suggesting post-hatching sampling in these grounds. N is sample size.

			Carapace Length (mm)			
Year / Ground	N	% Ovigerous	Mean	SE	Min.	Max.
2020	*138*	*23.9*	*81.2*	*1.1*	*37*	*105*
Mors/Fegge	62	21.0	82.2	1.8	37	105
Ejerslev Røn	66	25.8	80.8	1.3	40	97
2021	*1,209*	*18.6*	*75.7*	*0.4*	*41*	*115*
Mors/Fegge	4	0	75.7	1.0	57	104
Ejerslev Røn	202	24.8	75.5	10.2	41	107
Kås S	552	14.7	74.3	0.6	42	113
Kås Hoved	134	11.9	78.4	1.1	53	111
Venø Sund	315	24.8	77.3	0.9	41	115
*2022**	*1,102*	*19.0*	*82.3*	*0.4*	*48*	*126*
Mors/Fegge	23	17.4	81.2	2.5	53	102
Ejerslev Røn	93	20.4	80.5	1.3	52	122
Livø	106	44.3	91.1	1.1	69	119
Rønbjerg	93	23.7	80.0	1.0	59	104
Fur W	558	12.0	78.8	0.4	48	126
*Grynderup	65	*1.6	74.0	1.2	44	102
Nykøbing M	46	34.8	87.0	1.4	67	113
*Kås N	543	*6.1	81.9	0.3	60	127
*Kås Hoved	70	*4.5	79.7	1.2	48	105
*Jegind Tap	14	*0	75.7	2.1	55	85
*Venø Bugt	35	*8.6	79.2	1.3	62	95
*Venø Sund	152	*5.9	79.2	0.8	48	127
Nissum W	139	15.1	88.5	0.7	67	112
Nissum E	44	29.5	89.6	2.0	62	95
*Total**	*2,432*	*19.1*	*79.0*	*0.3*	*37*	*126*

Functional maturity

Functional maturity was determined from the proportion of ovigerous females relative to body size, a commonly used method (e.g. Tully et al., 2001; ICES, 2003), obtained from the direct observation of presence/absence of eggs under the abdomen of female lobsters (ovigerous status). Observation of ovarian conditions, another more accurate technique to estimate size at onset of maturity (ICES, 2003), was unpractical with the resources available requiring the capture and dissection of lobsters.

Functional maturity based on the ovigerous status should be determined per 1 mm size classes containing at least five individuals (ICES, 2003) and also assessed prior to the spawning and hatching periods in late spring, summer and autumn (Tully et al., 2001; ICES, 2003; Agnalt, 2007). Therefore, only data collected in the springs of 2020, 2021 and 2022 were used in maturity analysis, excluding catch also obtained in the summer and autumn seasons.

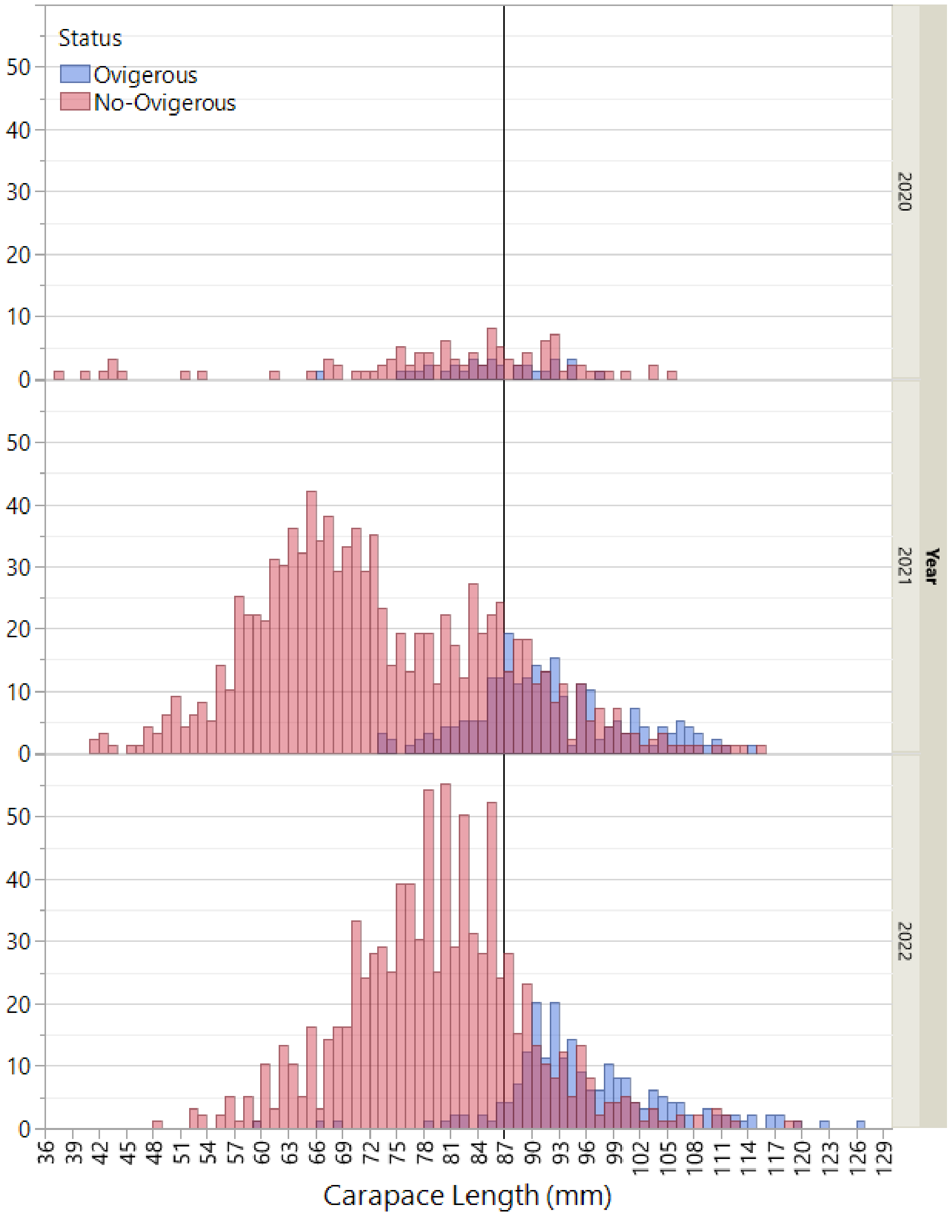

Figure 5.2. Histogram of carapace length (mm) of ovigerous and non-ovigerous female lobsters in the springs of 2020, 2021 and 2022.

A total of 3,326 female lobsters were measured, however due to the low prevalence of ovigerous females (<10%), several fishing grounds in 2022 were excluded from maturity analysis as it suggests sampling at these locations occurred after or during hatching (Figure 5.1 and Table 5.1). Therefore, a total of 2,432 female lobsters were used in maturity analysis ranging in size from 37 to 126 mm CL (Figure 5.2), of which 464 were ovigerous, with 123 female lobsters were measured in 2020, 1,207 in 2021 and 1,102 in 2022 (Table 5.1). The smallest ovigerous female observed in the entire catch data was 51 mm carapace length but is not part of the analysis as it was not caught in spring.

Size classes with less than nine individuals (Figure 5.3) were not included in the analysis to ensure increased robustness in the proportion of ovigerous females in the smallest and large size classes which inherently have small sample sizes.

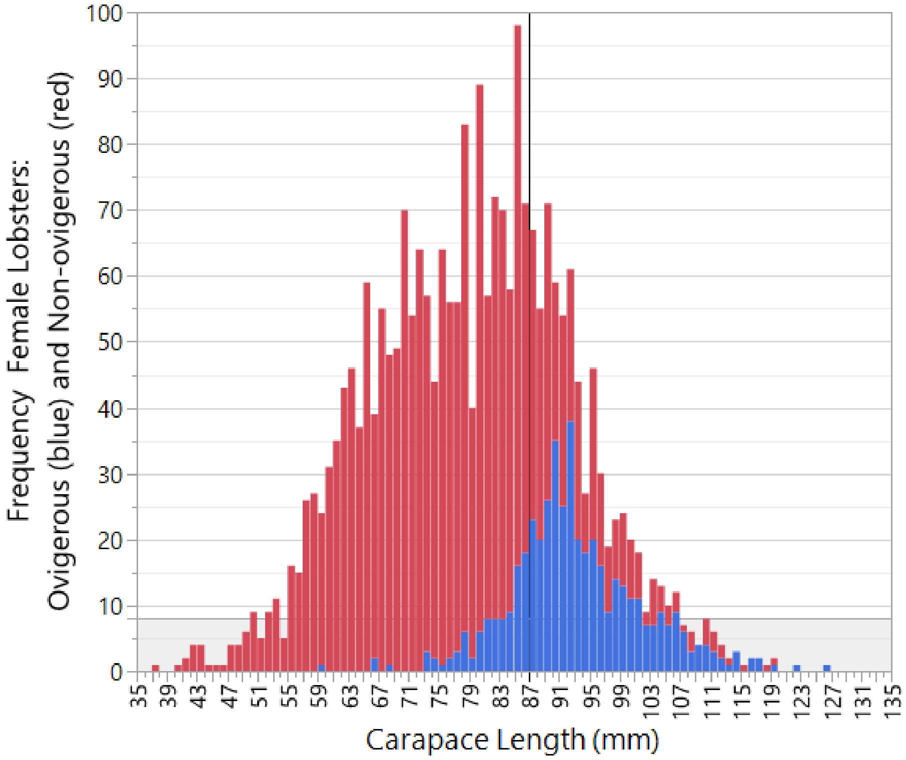

Figure 5.3. Stacked histogram of ovigerous (blue) and non-ovigerous (red) female lobsters per 1 mm carapace length (CL) size-classes. Black vertical line is the minimum landing size of 87 mm CL, while grey shaded area marks the small sample size exclusion limit (< 9 individuals per size class).

A logistic function was fitted to the relationship between the cumulative proportion functional maturity (P_{mi}, ovigerous ratio) and carapace length (CL_i) per 1 mm size classes, i.e. the maturity ogive. Size at first maturity was established as the average size when 50% ($CL_{50\%}$ for annual cycle) or 25% ($CL_{25\%}$ for biennial cycle, accounting for spawning and moulting in alternate years) of female lobsters become mature. Errors are 95% confidence intervals of the fit.

Reproductive potential

Reproductive potential was determined per 2 mm size classes using two indices (Morgan, 1982; Tully et al., 2001; Goñi et al., 2003; Agnalt et al., 2007): An index of absolute spawning potential (ISP_{Abs}) that is equal to potential total egg production, i.e. number of eggs; and an index of relative spawning potential (ISP_{CPUE}), which reflects potential egg production female relative to female catch per unit effort (CPUE), an indicator of female lobster abundance.

First, the relative reproductive potential (RRP, e.g. Tully et al., 2001) was determined in an intermediate step to calculate the two indices as:

$$RRP = F_i * Pm_i * N_i$$

Where F_i is the fecundity of size class *i*, Pm_i is the proportion of functionally mature lobsters (i.e. ovigerous) in size class *i* and N_i is the number of female lobsters in size class *i* expressed as the percentage of total female sample size.

Fecundity (F_i, egg production) was calculated using the power fit model to carapace length (CL_i) from Agnalt (2008) for the number of eggs produced by female lobsters of a given size in Southeast Norway:

$$F_i = 0.0045\ CL_i^{3.22}$$

Where F_i is the number of eggs produced and CL_i is carapace length in size class *i*. A power fit model is considered more appropriate than linear models to explain the relationship between body size and egg mass or number (ICES, 2003).

Pm_i was obtained from the size at maturity results from this study. Low sample sizes did not allow to robustly estimate Pm_i at each location, and thus Pm_i is assumed to be the same across the Limfjorden, i.e. the proportion of mature females at any given size is the same at all locations. Therefore, RRP only reflects differences in reproductive potential due to female size distribution.

The index of absolute spawning potential (ISP_{Abs}), was determined by using the absolute number of female lobsters in size class *i* as N_i:

$$ISP_{Abs} = F_i * Pm_i * N_{iAbs}$$

ISP_{Abs} is equal to total egg production and can only be determined when the absolute female population is known and depends both on female size distribution and absolute abundance of female lobsters.

The index of relative spawning potential (ISP_{CPUE}), was determined by using female CPUE (lobster/pot/day) in size class *i* as N_i:

$$ISP_{CPUE} = F_i * Pm_i * CPUE_i$$

Mean monthly female CPUE were standardized relative to a reference temperature of 15°C to account for temperature related changes in catchability. Mean CPUE was then multiplied by N_i (i.e. the percentage of total female sample size in size class *i*) to obtain $CPUE_i$. ISP_{CPUE} reflects potential egg production relative to female CPUE, which is used as an indicator of lobster abundance. ISP_{CPUE} depends on female size distribution and relative abundance of female lobsters, not absolute, and thus indicates potential egg production. ISP_{CPUE} allows comparison of potential egg production between different populations or fishing grounds, or at different times, e.g. for the same ISP_{CPUE} if one ground has twice the area than another, it will produce twice the number of eggs.

ISP_{Abs} was only calculated for two sites where absolute female lobster population was known in summer 2021 (Figure 5.1): the protect Livø MPA and the immediately adjacent Livø non-MPA where fishing is allowed, but that is affected by the MPA (Petersen et al., 2022). Even though ISP_{Abs} could not be determined for other locations, it provides a comparison baseline for ISP_{CPUE} between Livø MPA and Livø non-MPA with fished grounds in 2021 and 2022.

ISP_{CPUE} was calculated for four areas in summer-autumn 2021: the mentioned Livø MPA and Livø non-MPA, and two fishing grounds, Ejerslev-Mors in western Løgstør Bredning and Kås Syd in the southern part of Kås Bredning (Figure 5.1). In spring 2022, ISP_{CPUE} was calculated for six fishing grounds in a broad NE-SW transect of the Limfjorden (Figure 5.1): Løgstør E close to Rønbjerg;

Løgstør C in the vicinity of Livø MPA and includes but is larger than the Livø non-MPA sampled in 2021; Ejerslev-Mors as described above; Fur W in the western part of Fur island; Venø S in Venø Sund to the east of Venø island; and Nissum N in two locations on the northern coast of Nissum Bredning.

Different fishing gear was used at different sites, but size selectivity is assumed to be the same: Multi-pots (Løgstør E and C, Ejerslev, and Fur W), eel fyke nets (Venø S) and pots (Livø MPA and non-MPA, Nissum N). Pots used in Nissum Bredning had escape vents and thus distribution is truncated for sizes smaller than ca. 79 mm CL. Catches by multi-pots and eel fyke nets were converted to pot equivalent CPUE using conversion factors obtained in the present project in efficiency calibration trials (Chapter 8, this report): one multi-pot equals 4.62 pots and one eel fyke net equals 3.22 pots.

5.3 Results

Maturity

The highest proportion of ovigerous females per size-class was ca. 85% at 108 mm CL, and 12 other size-classes showed between 50 and 75% for sizes between 90 to 107 mm (Figure 5.4). The logistic fit of proportion ovigerous and size was:

$$P_{mi} = \frac{1}{1 + \mathrm{e}^{(-\mathrm{a}*(\mathrm{CLi}-\mathrm{b})}}$$

Where P_{mi} is the ovigerous ratio and CL_i is the carapace length of size-class *i*; a is the growth rate and equals 0.1197 ±0.0166 (95% CI) and b is the inflection point and equals 95.640±1.135 (95% CI); N = 2,365).

The logistic fit was used to estimate $CL_{50\%}$ at 95.64 ±1.14 mm (95% CI) and $CL_{25\%}$ at 86.46 ±1.52 mm CL (95% CI; Figure 5.4). 100% of female lobsters would be mature at 140 mm CL.

The MLS of 87 mm CL is 8.6 mm lower than $CL_{50\%}$ and just 0.5 mm above $CL_{25\%}$ and corresponds to 26.3% of female lobsters being functionally mature.

In the most recent fishing season of spring 2022, 50% of lobsters landed in the Limfjorden (i.e. excludes lobsters smaller than 87 mm CL and berried females) were obtained by 92 mm CL as indicated by the cumulative length distributions for both female and male lobsters (Figure 5.5). A carapace length of 92 mm is 3.6 mm shorter than $CL_{50\%}$ and 5.5 mm above $CL_{25\%}$ and corresponds to 39.3% of female lobsters being functionally mature.

Therefore, 50% of landings are realized with between 26.3 and 39.3% of female lobsters being functionally mature. 68% of landings are obtained from carapace lengths shorter than $CL_{50\%}$, but no landings were obtained at $CL_{25\%}$ as it is shorter than MLS (Figure 5.5).

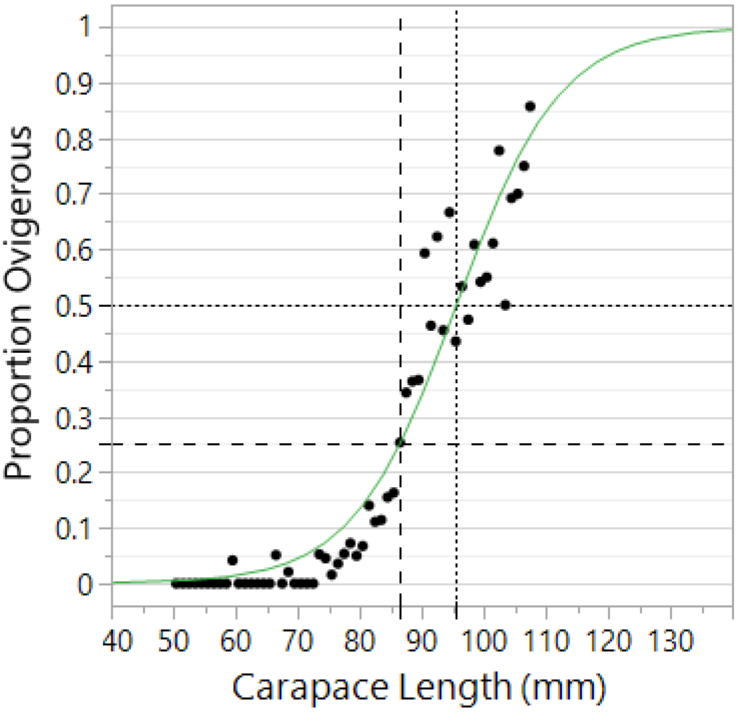

Figure 5.4. The maturity ogive obtained from a logistic model fitted to the proportion of ovigerous female lobsters relative to body size (1 mm carapace length classes). $CL_{50\%}$ was estimated at 95.64 ±1.14 mm CL (95% CI; dotted lines) and $CL_{25\%}$ at 86.46 ±1.52 mm CL (95% CI; dashed lines).

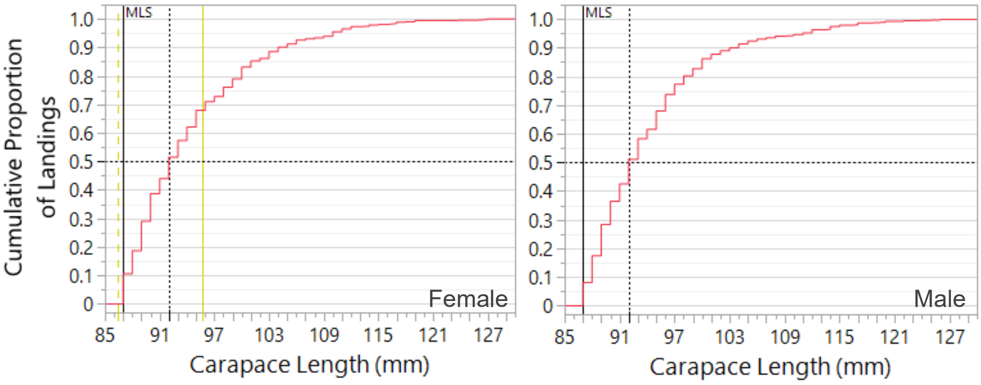

Figure 5.5. The cumulative carapace length (mm) distribution of landings for female (left) and male (right) lobsters in the spring of 2022. Dashed lines indicate 92 mm carapace length at which 50% of landings are obtained for both female and male lobsters. Yellow lines indicate $CL_{50\%}$ (solid) and $CL_{25\%}$ (dashed) for female lobsters. Solid vertical black line is the 87 mm MLS.

Reproductive potential

Absolute egg production

ISP_{Abs}, i.e. total egg production, in all but one size classes was higher in the Livø MPA than in the Livø non-MPA (Figure 5.6). ISP_{Abs} in the protected Livø MPA showed two modal size classes at 95–97 and 109–111 mm CL, while in the adjacent Livø non-MPA, ISP_{Abs} showed two modal size classes at 87–89 and 103–105 mm CL (Figure 5.6). Nevertheless, the cumulative distribution of ISP_{Abs} with carapace length did not differ between Livø MPA and Livø non-MPA (Kolmogorov-Smirnov test for equal distribution, $D(35) = 0.257$, $p = 0.168$) and 50% of egg production occurred by similar sizes of 97–99 mm CL (Figure 5.6).

By the MLS of 87 mm CL the proportion of total egg production was 9% and 6% % in Livø MPA and Livø non-MPA, respectively, and thus most of reproductive potential /egg production originated from lobsters larger than MLS (Figure 5.6, Table 5.2).

Total number of eggs produced in the fished Livø non-MPA, but still affected from the spillover of lobsters from the protected area, were 56% lower than in the protected Livø MPA, estimated at 3,284,180 ±1,196,281 eggs (95% CI) and 1,455,549 ±992,763 eggs (95% CI) respectively (Figure 5.7, Table 5.2).

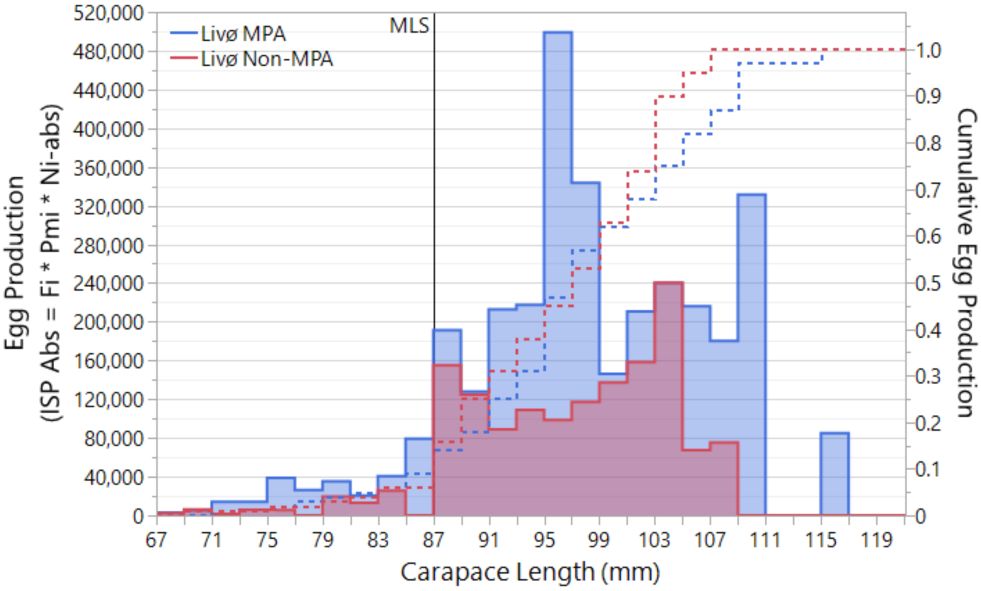

Figure 5.6. Absolute index of spawning potential (ISP$_{Abs}$) equal to egg production per 2 mm size classes and cumulative egg production (dashed line) during late summer 2021 (Figure 5.1) in the Livø MPA and adjacent Livø non-MPA. Egg production can only be estimated when the absolute population of female lobsters is known. Black vertical line marks minimum landing size (MLS) at 87 mm CL.

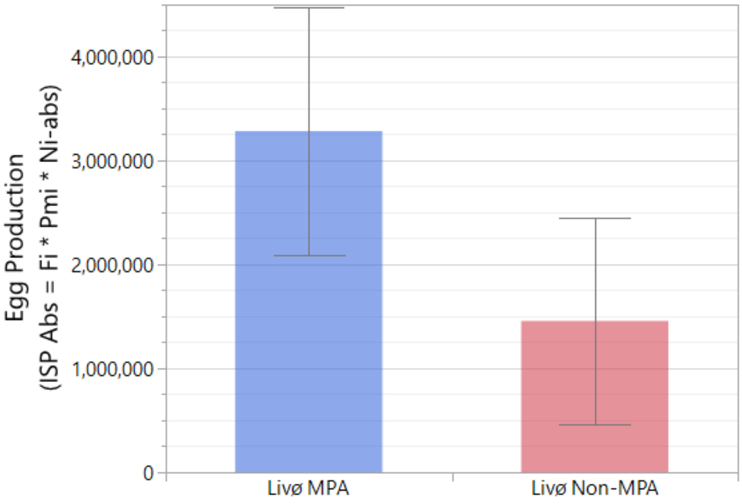

Figure 5.7. Absolute index of spawning potential (ISP$_{Abs}$) equal to total egg production of the population in the protected area Livø MPA and adjacent non protected Livø non-MPA in the summer of 2021 (Figure 5.1).

Protected and fished areas

ISP$_{CPUE}$ distribution in the Livø MPA and adjacent Livø non-MPA paralleled their ISP$_{Abs}$ distribution since both absolute female population and female CPUE are ca. twice higher in the former area.

ISP_{CPUE} in all but one size classes were higher in the protected Livø MPA, with lower values in the Livø non-MPA. ISP_{CPUE} in the fished grounds Ejerslev-Mors and Kås Syd reached at most 35 %to 15% of ISP_{CPUE} values in the other two sites (Figure 5.8).

Table 5.2. Reproductive potential in the Limfjorden in the summer-autumn 2021 and spring 2022. In 2021, a protected area with no fishing (Livø MPA) was compared to three fished areas, the adjacent area (Livø non-MPA) affected by spillover from the protected area (project Miljøstyrelsen, J.nr. MST-4-00064) and two fishing grounds on western Løgstør Bredning (Ejerslev-Mors) and Kås Bredning (Kås Syd). In 2022, six fished grounds were compared in a broad NE-SW transect across the Limfjorden as described in Figure 5.1. RRP: Relative reproductive index; ISP_{Abs}: Absolute index of spawning potential, equal to egg production; ISP_{CPUE}: index of relative spawning potential. *Pot equivalent CPUE (lobster/pot/day): Catch of different types of gear were converted to pot equivalent CPUE. $^{+}$Pots used in Nissum N had escape vents and distribution is truncated for sizes smaller than ca. 79 mm CL.

Year / Ground	Fishing Gear	N	Female Population	*CPUE	RRP	ISP_{Abs}	Total ISP_{CPUE}	<MLS ISP_{CPUE}	>MLS ISP_{CPUE}
Summer-Autumn 2021									
Livø MPA	Pots	211	964 ±276	0.295 ±0.041	3,407 ±266	3,284,180 ±1,196,281	1,006 ±130	62 ±6	944 ±123
Livø non-MPA	Pots	79	452 ±272	0.139 ±0.033	3,220 ±259	1,455,550 ±992,763	447 ±99	25 ±5	422 ±94
Ejerslev-Mors	Multi-pots	270		0.177 ±0.027	1,474 ±174		260 ±36	74 ±9	186 ±27
Kås Syd	Multi-pots	255		0.135 ±0.063	1,051 ±140		142 ±57	52 ±18	90 ±39
Spring 2022									
Løgstør E	Multi-pots	93		0.073 ±0.013	1,705 ±195		124 ±20	27 ±4	97 ±73
Løgstør C (Livø)	Multi-pots	106		0.066 ±0.035	4,122 ±297		274 ±135	12 ±5	261 ±130
Ejerslev-Mors	Multi-pots	116		0.191 ±0.040	2,279 ±213		435 ±83	57 ±9	378 ±74
Fur W	Multi-pots	233		0.114 ±0.017	1,380 ±173		157 ±20	48 ±5	109 ±15
Venø S	Eel Fykenets	60		0.043 ±0.032	1,462 ±181		63 ±41	21 ±12	42 ±29
$^{+}$Nissum N	Pots	183		0.058 ±0.008	3,983 ±313		229 ±31	22 ±3	207 ±29

ISP_{CPUE} increased with lobster size in the protected Livø MPA and adjacent Livø non-MPA, being highest at sizes larger than the 87 mm CL MLS, particularly in the protected Livø MPA (Figure 5.8, Table 5.2). In the two fished grounds Ejerslev-Mors and Kås Syd, ISP_{CPUE} did not vary greatly with lobster size ranging between 10 and 20 at sizes larger than ca. 75–79 mm Cl (Figure 5.8).

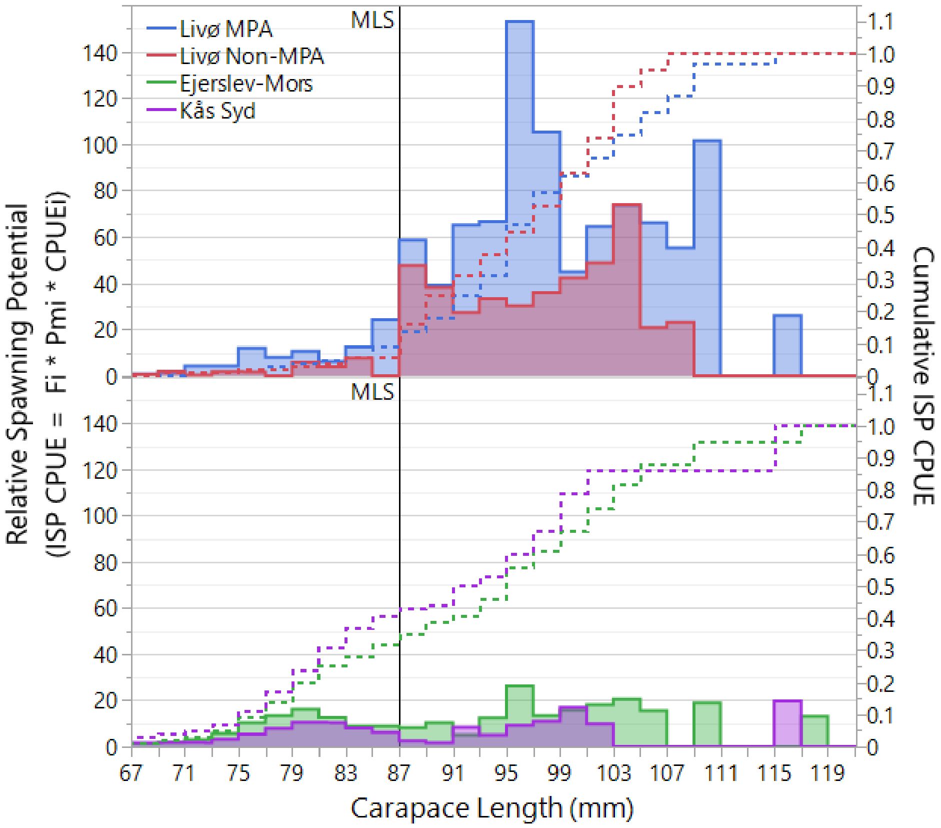

Figure 5.8. Relative index of spawning potential (ISP$_{CPUE}$) per 2 mm size classes and cumulative proportion ISP$_{CPUE}$ (dashed line) at four locations during late summer-autumn 2021 (Figure 5.1): Top: 1) Livø MPA and 2) Livø non-MPA. Bottom: Two fishing grounds, 3) Ejerslev-Mors in and 4) Kås Syd. Black vertical line marks minimum landing size (MLS) at 87 mm CL.

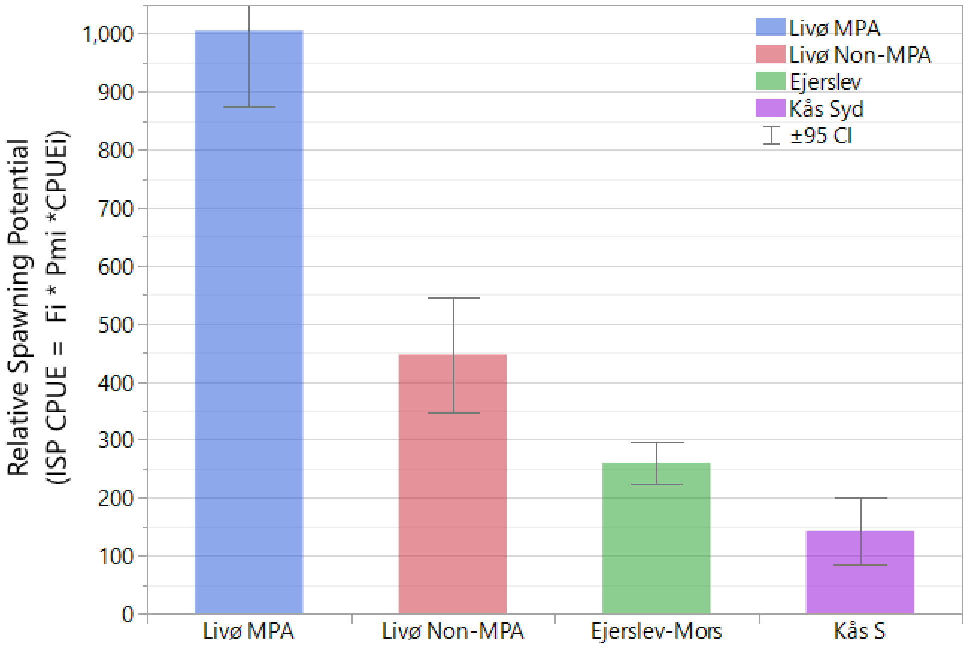

Figure 5.9. Relative index of spawning potential (ISP$_{CPUE}$) at four locations during late summer-autumn 2021 (Figure 5.1): the protected Livø MPA, and three fished grounds, non-protected Livø non-MPA, Ejerslev-Mors and Kås Syd (Figure 5.1).

As with $\mathrm{ISP}_{\mathrm{Abs}}$, cumulative distribution of $\mathrm{ISP}_{\mathrm{CPUE}}$ with carapace length did not differ between Livø MPA and Livø non-MPA (K-S test for equal distribution, $D(35) = 0.257$, $p = 0.168$) (Figure 5.8), but differed between Livø MPA and the two other distant fished areas Ejerslev-Mors and Kås Syd (K-S test for equal distribution, $D(36) = 0.361$, $p = 0.013$ and $D(36) = 0.4$, $p = 0.005$) (Figure 5.8). The fished grounds, including Livø non-MPA, differed in cumulative distribution of $\mathrm{ISP}_{\mathrm{CPUE}}$ with carapace length at a significance $p < 0.1$ (K-S test for equal distribution, $D(34–35) = 0.286–0.324$, $0.044 < p < 0.094$).

The contribution of lobsters smaller than the MLS of 87 mm CL, was 9% and 6% of total $\mathrm{ISP}_{\mathrm{CPUE}}$ in the Livø MPA and adjacent Livø non-MPA, but 32 and 41% of total $\mathrm{ISP}_{\mathrm{CPUE}}$ in Ejerslev-Mors and Kås Syd (Figure 5.8, Table 5.2). Cumulative $\mathrm{ISP}_{\mathrm{CPUE}}$ reached 50% of egg production by similar sizes of 97–99 mm CL in the Livø MPA and adjacent Livø non-MPA, while in the fished areas Ejerslev-Mors and Kås Syd 50% of egg production was reached by 91–93 and 95–96 mm CL (Figure 5.8).

Total $\mathrm{ISP}_{\mathrm{CPUE}}$ was highest in the Livø MPA at 1,006 ±130 (95% CI), 56% lower in the adjacent Livø non-MPA at 447±99 (95% CI), and 74% and 86% lower in the two other fished grounds Ejerslev-Mors and Kås Syd, at 260 ±36 (95% CI) and 142 ±57 (95% CI) respectively (Figure 5.9, Table 5.2).

Spring 2022

$\mathrm{ISP}_{\mathrm{CPUE}}$ reached higher values in the north-eastern sites of Ejerslev-Mors with up to 70 and in Løgstør C with up to 40, western Nissum N reached $\mathrm{ISP}_{\mathrm{CPUE}}$ values close to 30, while Løgstør C, the central Fur W and southern Venø S reached at most $\mathrm{ISP}_{\mathrm{CPUE}}$ values of 10 to 20 (Figure 5.10).

$\mathrm{ISP}_{\mathrm{CPUE}}$ increased with lobster size in the north-eastern sites in Løgstør Bredning, Løgstør E, Løgstør C and Ejerslev-Mors, being highest between 91–107 mm CL (Figure 5.10). In the other three fished grounds, central Fur W, southern Venø S and western Nissum N, $\mathrm{ISP}_{\mathrm{CPUE}}$ did not vary greatly with lobster size usually, ranging between 10 and 20 at sizes larger than ca. 77–79 mm Cl (Figure 5.10).

Cumulative $\mathrm{ISP}_{\mathrm{CPUE}}$ reached 50% of total reproductive potential egg production by 91–95 mm CL at four sites, Løgstør E, Ejerslev-Mors, Fur W and Venø S, and at Løgstør C by 97-99 mm CL and at Nissum N by 99-101 mm CL, although the latter is biased to larger lengths due to size truncation at ca. 79 mm CL by escape vents in gear (Figure 5.10).

The contribution of lobsters smaller than MLS to total $\mathrm{ISP}_{\mathrm{CPUE}}$, was lowest in Løgstør C at 9%, with intermediate values of 17% in Ejerslev-Mors and 25% in Løgstør E, and higher values of 36% in Fur W and 34% Venø S (Figure 5.10, Table 5.2). In Nissum N it was 17%, an underestimation due to size truncation at ca. 79 mm CL by escape vents in gear.

Total $\mathrm{ISP}_{\mathrm{CPUE}}$ was highest in Ejerslev-Mors at 435 ±83 (95% CI), intermediate in Løgstør C at 273 ±135 (95% CI) and Nissum N at 229 ±31 (95% CI), lower in Løgstør E at 124 ±20 (95% CI), Fur W at 157 ±20 (95% CI) and lowest in Venø S at 63 ±41 (95% CI) (Figure 5.11, Table 5.2). In Nissum Bredning, the use of escape vents in the fishing gear underestimated $\mathrm{ISP}_{\mathrm{CPUE}}$ by at most 15% based on the other fishing grounds.

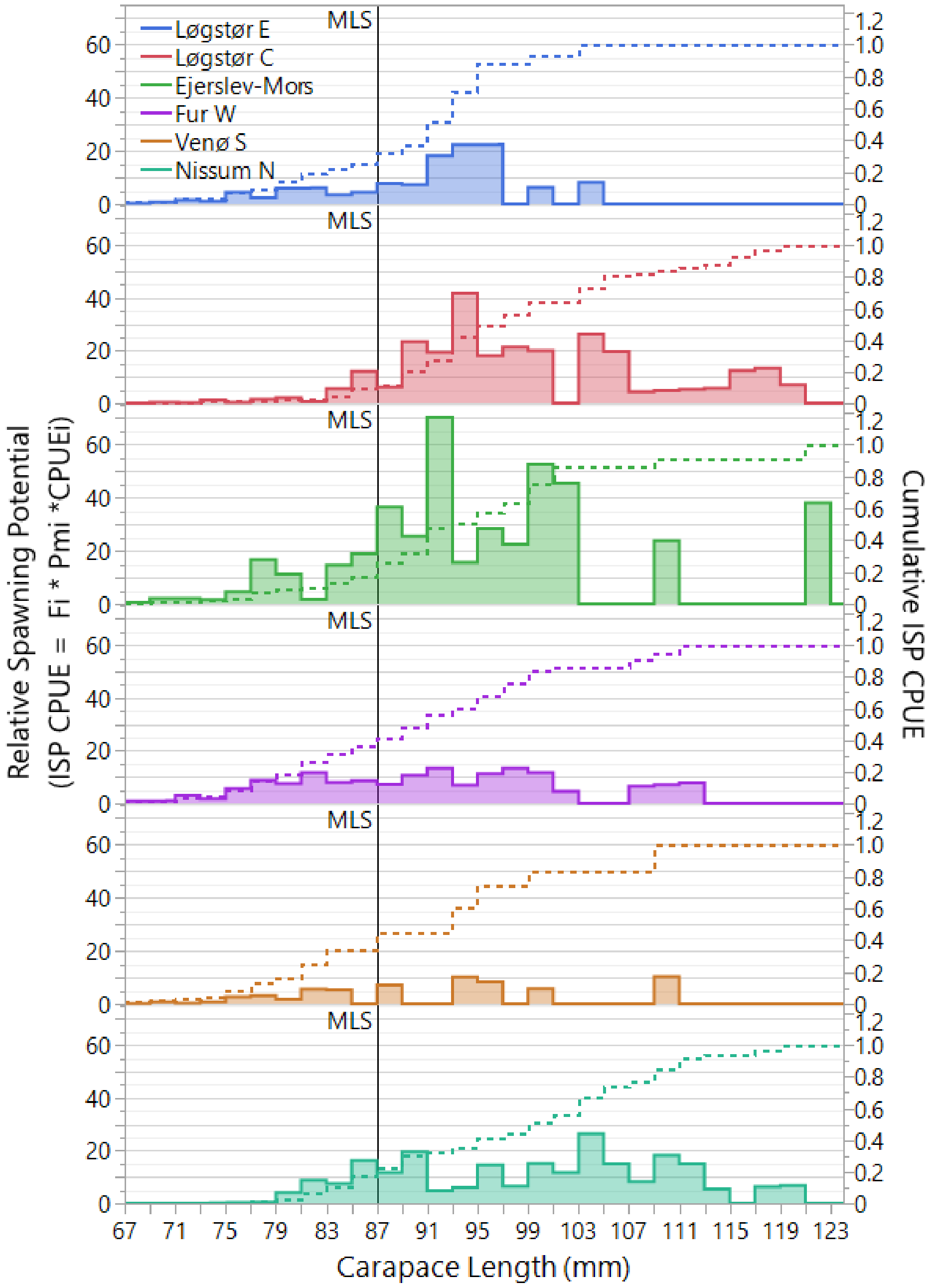

Figure 5.10. Relative index of spawning potential (ISP_{CPUE}) per 2 mm size classes and cumulative proportion ISP_{CPUE} (dashed line) at the six locations during spring 2022 (Figure 5.1): Løgstør E; Løgstør C in the vicinity of Livø MPA, which includes but is larger than the Livø non-MPA site; Ejerslev-Mors; Fur W; Venø S; and Nissum N. *Pots used in Nissum had escape vents and thus distribution is truncated for sizes smaller than ca. 79 mm CL. Black vertical line marks minimum landing size (MLS) at 87 mm CL.

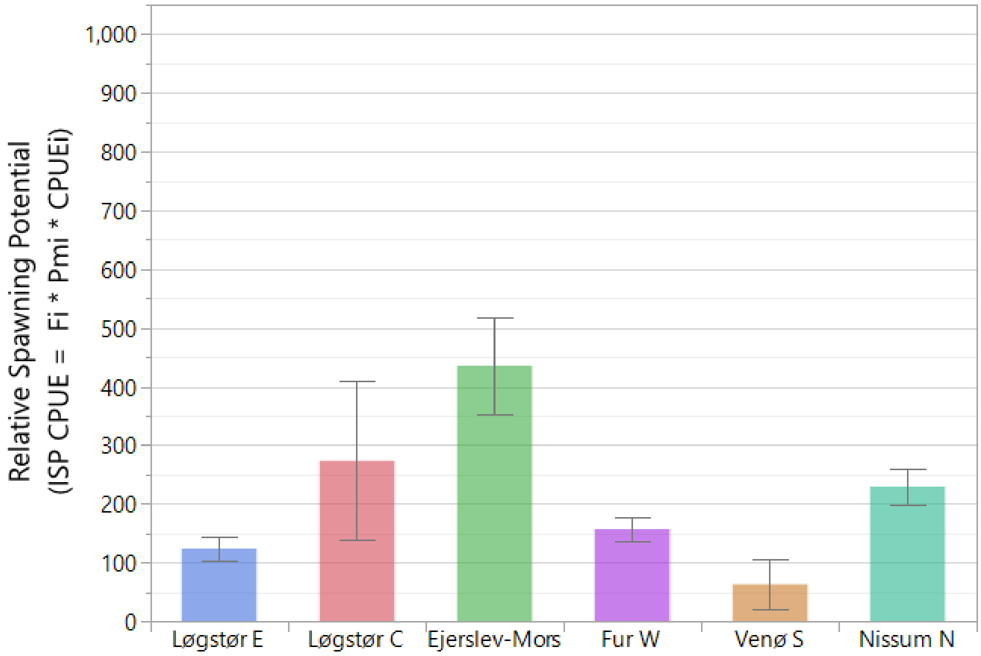

Figure 5.11. Relative index of spawning potential (ISP$_{CPUE}$) at six fishing grounds in a broad NE-SW transect across the Limfjorden during spring 2022 (Figure 5.1): Løgstør E; Løgstør C in the vicinity of Livø MPA, which includes but is larger than the Livø non-MPA site; Ejerslev-Mors; Fur W; Venø S; and Nissum N.

5.4 Discussion

Maturity

The reproductive cycle of European lobsters can be annual, spawning once a year (e.g. Latrouite et al., 1981, 1984; Tully et al., 2001; Laurans et al., 2009; Wood, 2018), or biennial, spawning and moulting in alternate years (e.g. Tully et al., 2001; Agnalt et al., 2007). However, the occurrence of a biennial cycle over the entire European lobster geographical distribution and at all sizes is far from certain, being spatially variable even at small scale and is more likely with increasing size in large lobsters (>ca, 100-105 mm; e.g. Tully et al., 2001; Agnalt et al., 2007; Coleman et al., 2021). For instance, at several locations almost all lobsters, including large lobsters (>115 mm CL) were in an annual cycle (Laurans et al., 2009) and still undergo double moulting in a year (Bennett et al., 1978; Coleman et al., 2021). For a given population, determining if lobsters follow an annual or a biennial reproductive cycle is fundamental as it significantly affects size-at-maturity estimations. In an annual cycle, the size at first maturity (functional) is equal to the size when 50% of the females are ovigerous, while in a biennial cycle it is equal to the size when 25% of females are ovigerous since only half of mature females are expected to be ovigerous each year.

Some studies have used the maximum proportion of ovigerous females has indicative of a biennial cycle if low, remaining below 50% or never reaching 100% (e.g. Tully et al., 2001; Ulmestrand in ICES 2003) or an annual cycle if high (e.g. Latrouite et al., 1981, 1984; Laurans et al., 2009; Wood, 2018). However, several factors contributed to lower the observed proportion of ovigerous females in the population and lead to the assumption of a biennial cycle based on the maximum proportion of ovigerous females being low (e.g. Tully et al., 2001; Ulmestrand in ICES 2003). First, the incorporation of periods of the year after spawning and before hatching of eggs lowers the observed proportion of ovigerous females in the population (ICES, 2003; Laurans et al., 2009). Secondly, spawning and hatching are unlikely to be synchronized to occur at a specific time of the year as seen in the presence of berried females throughout the year (Laurans et al., 2009). Thirdly, berried lobsters are expected to have a lower catchability than non-berried females (Branford, 1979; Agnalt et al., 2007), and thus are underrepresented in catches of female lobsters. Therefore, similarly to the view of Laurans et al. (2009), those studies most likely underestimated the proportion of mature females that become ovigerous each year.

Considering: 1) the increased probability of double moulting at sizes <90 mm CL (Bennett et al., 1978); 2) the probability of double moulting in a year decreases with size, but can occur up to 130 mm in some locations (Coleman et al., 2021); 3) that European lobsters similarly to their close relative the American lobster, likely can retain and use sperm for several years until fertilization (Talbot and Helluy, 1995) and 4) can mate while hard-shelled outside intermoult periods (Dunham and Skinner-Jacobs, 1978; Waddy and Aiken, 1990). Thus, in European lobster populations with high proportion of ovigerous females, most lobsters with sizes close to or even higher than MLS can be expected to follow an annual cycle. The proportion of functionally mature female lobsters (i.e. ovigerous) per mm carapace length in the Limfjorden was found to be high, reaching 85% and often between 50–75 % (Figure 5.4). Therefore, the European lobster population in the Limfjorden is considered to follow an annual reproductive cycle and $CL_{50\%}$ is the correct estimator of size at first maturity.

Large differences in European lobster $CL_{50\%}$ functional maturity have been described in the North Atlantic and North Sea regions (e.g. Latrouite et al., 1981, 1984; Tully et al., 2001; ICES, 2003; Laurans et al., 2009; Wood, 2018; ICES, 2021; SIFCA, 2021) ranging from 83–100 mm CL on the eastern coast of the UK (Free et al., 1992), 103–106 mm CL in northern France (Laurans et al., 2009), 107–140 mm CL in Ireland (Tully et al., 2001). The lowest value reported in the literature was 79 mm CL from the west coast of Sweden (Ulmestrand in ICES, 2003). Some of these studies assumed a biennial reproductive cycle (e.g. Tully et al., 2001; Ulmestrand in ICES, 2003; Agnalt et al., 2007), which significantly reduced size at 50% maturity. In the Limfjorden, $CL_{50\%}$ functional maturity was 95.6 ±1.1 mm (95% CI) and within the range described for other locations, particularly in Ireland (Tully et al., 2001), northern France (Latrouite et al., 1981, 1984) and eastern UK (Wood, 2018).

Size at the onset of maturity is an essential parameter for the sustainable management of an exploited stock, which aims to ensure sufficient egg production and avoid fishing mortality of immature juvenile individuals. In lobsters, as in other animals, size at first maturity is considered the relevant reference point to establish minimum legal sizes of landings (e.g. Tully et al. 2001, Tully 2004; Tully 2006; Wood, 2018). Currently, lobster fishing in the Limfjorden is limited by an MLS of 87 mm CL set in 2002 for European wide waters (EU Regulation 2019/1241) except for the Mediterranean Sea (105 mm CL/ 300 TL), Skagerrak and Kattegat (78 mm CL or 220 mm TL). Nevertheless, several countries have increased MLS either nationally (e.g. Norway, 250 mm TL or ca. 91 mm CL; Sweden, 90 mm CL), or regionally (e.g. UK and France, 90 mm CL) for increased protection of spawning biomass and egg production.

In the Limfjorden, $CL_{50\%}$ was 95.6 ±1.1 mm (95% CI) and thus 8.6 mm larger than the MLS of 87 mm. At 87 mm only 26.3% of females were functionally mature and thus a high proportion of landings are taken from sizes smaller than $CL_{50\%}$, the reference point when 50% of females are functionally mature. Lobster landings in the Limfjorden in 2022 indicate that 68% of landings were realized from sizes smaller than $CL_{50\%}$ (Figure 5.5).

The use of ovigerous status (egg bearing) can underestimate functional maturity – due to e.g. females may not carry eggs when sampled, but reproduced that year; season of sampling; lack of synchronization of spawning and hatching; reduced catchability of berried females – leading to overly conservative estimates (Tully et al., 2001; Laurans et al., 2009; Wood, 2018). In lobster fisheries where berried females are protected, the reverse occurs as the removal of non-berried females larger than MLS biases the proportion of ovigerous females in the population, increasing the ovigerous ratio.

Therefore, the future management of the lobster population and fishery in the Limfjorden should include: continued collection of maturity data to improve accuracy of estimate; assess the timing of spawning, hatching and moulting in the estuary to ensure data is collected at the correct time of the year; assess differences in catchability of berried and non-berried female lobsters with the different fishing gear used in the Limfjorden fishery; initiate a program to assess the more time consuming and intrusive ovarian condition method for comparison with the ovigerous method as recommended by ICES (2003); assess male lobster maturity.

Reproductive potential

Understanding the impact of fishing on the reproductive potential of fished lobster stocks is essential to ensure sufficient egg production and viability of fisheries (e.g. Tulli et al., 2001; ICES, 2003; Goñi et al., 2003). Fishing impacts can affect reproductive potential by both truncating size distribution, i.e. removing large and more fecund females, and reducing abundance of lobster populations (e.g. Tulli et al., 2001; Goñi et al., 2003; Tulli et al., 2006; Agnalt et al., 2007; Hoskins et al., 2011). Therefore, assessing the reproductive potential and egg production in protected areas or at least in areas under low fishing pressure, allows to assess the relative contribution of different size classes to reproductive potential without the fishing-induced bias towards smaller sizes and lower abundances (e.g. Goñi et al., 2003; Tulli et al., 2006).

A clear effect from fishing protection on the reproductive potential of lobster populations was evident both in differences in absolute spawning potential (ISP_{Abs}), i.e. absolute egg production, or relative spawning potential (ISP_{CPUE}, egg production relative to CPUE) between a small (ca. 0.29 km^2) protected area, albeit still exposed to low fishing mortality (project Miljøstyrelsen, J.nr. MST-4-00064), when compared to a similar sized non-protected area outside and immediately adjacent to it or to distant fishing grounds (Figures 5.7 and 5.9; Table 5.2). Such effect was clear even though the adjacent non-protected area was affected by spillover from the protected area and thus had a more abundant population with larger sized lobsters than other distant unaffected fished grounds.

Total egg production (ISP_{Abs}) of 3.28 mio. eggs (or 3.4 mio. eggs per 1,000 female lobsters) in the protected area was significantly higher (2.3 times) than in the non-protected area, originating from higher lobster abundance in the protected area (Figure 5.7, Table 5.2). In only three years since the establishment of the protected area surrounding the Livø stone reef (2018 to 2021), protection from fishing resulted in an increase in total relative egg production (ISP_{CPUE}) of 3.9–7.1 times relative to fished grounds (Figure 5.9 and Table 5.2). These results, however, do not represent the loss of eggs per recruit due to fishing mortality relative to the protected area, i.e. the reduction on the average egg production of single individual female lobster over its lifetime before it is captured or dies of natural causes. Egg per recruit models are widely used in the management of lobster fisheries setting a proportion of egg production in the absence of the fishery or in lightly fished populations as a reference point to avoid recruitment overfishing, e.g. 10% in the USA American lobster fishery and in the Irish European lobster fishery (e.g. ICES, 2003; Tully et al., 2004, 2006; Miller and Hannah, 2006).

The reduced spawning potential and egg production in fished areas was associated with both a decrease in lobster abundance but also in size, with a strong reduction in the abundance of females larger than MLS as observed in other lobster species (e.g. Lyons eta 1981, Campbell and Robinson, 1983; Kelly et al 2000). Fishing led to a flattening of egg production potential distribution with size relative to the protected area, where population egg production increases with size (Tully et. al., 2001; Goñi et al., 2003). Fishing mortality reduced egg production of the harvestable fraction larger than MLS by 80.3–90.5% relative to the protected area and increased the dependence on lobsters smaller than MLS for egg production, 32–41% of total ISP_{CPUE} relative to 9% in the protected area (Figure 5.9 and Table 5.2).

Several factors, however, may be acting on multi-year timescales toward increased reproductive potential of European lobsters at smaller body size. Firstly, fecundity of female European lobsters at their northern distribution may increase with increasing temperature and latitude similarly to its close relative the American Lobsters *Homarus americanus* (Currie and Schneider, 2011). Although for European lobsters, fecundity was correlated with annual temperature range (Ellis et al., 2015), which is likely increasing due to climate change related higher temperature in summer. Secondly, size at maturity of American lobsters decreases with increasing temperatures (Le Bris et al., 2017), and the same may occur with the European lobster. Thirdly, size selection induced by sex-specific fishing mortality, i.e. preferential removal of larger male lobsters, was proposed to accelerate evolution towards smaller body size (Haar et al., 2017; Sørdalen et al., 2018).

Regarding reproductive potential across the Limfjorden in the spring of 2022, relative egg production ISP_{CPUE} varied by a factor of seven indicating variability in different fishing grounds. The high ISP_{CPUE} in Løgstør C likely reflected a positive spillover effect on size and abundance of the Livø MPA protected area, which it surrounds. The 67% increase in ISP_{CPUE} in Ejerslev-Mors between autumn 2021 and spring 2022 reflected the growth of a significant juvenile cohort (Chapter 4, this report) and also increased abundance (i.e. CPUE; Petersen et al., 2022), but nevertheless it was still 43% of the protected area ISP_{CPUE} in 2021. However, in the future CPUE estimates in different fishing grounds must be better constrained and improved to account for differences in fishing efficiency of different gear, variable soaking times, as well as differences in temperature and season. Alternatively, a standardized fishing protocol using the same type of gear, soak times with monitoring of temperature could be used.

A clear impact on the reproductive potential of lobsters was evident after only three years since protection from fishing was implemented, being higher by a factor of 4 to 7 than in fished areas. 50% of egg production was usually reached at a size 4 to 9 mm or 1 to 2 moult increments larger than MLS (Wahle et al., 2013 and references therein). Egg production in the Limfjorden lobster population currently relies on small lobsters that are less fecund and with lower proportion of mature females (Agnalt et al., 2008), and produce smaller and less viable eggs (Moland et al 2010) than larger lobsters. The dependence on small sizes below or just above MLS increases the exposure of egg production in the Limfjorden lobster population to the impacts of poor recruitment or increases in fishing mortality. This study cannot however determine if current egg production is sufficient or insufficient to sustain recruitment and renewal of the lobster population in the Limfjorden.

5.5 Conclusions

This study was a first attempt to quantify European lobster size at the onset of maturity and reproductive potential in the Limfjorden. European lobsters were found to follow an annual reproductive cycle with the proportion of ovigerous females reaching up to 85% at 107 mm carapace length in spring. Size at first maturity or at the onset of maturity ($CL_{50\%}$) when 50% of females become mature was 95.6 ±1.1 mm (95% CI) carapace length and thus 8.6 mm larger than minimum landings size. At minimum landing size only 26% of females were mature and in 2022 a high proportion of landings, 68%, were obtained from sizes smaller than $CL_{50\%}$.

Reproductive potential in the Limfjorden was 74–86% lower in fished areas than in a small, protected area, albeit still exposed to low fishing mortality, due to both lower abundance and smaller size of lobsters. Egg production in the Limfjorden lobster population relies mainly on small lobsters, with 50% of egg production originating from lobsters smaller than 91–96 mm, just 4–9 mm larger than minimum landing size. This study, however, could not ascertain if current egg production levels in the Limfjorden are sufficient or insufficient to sustain recruitment and renewal of the lobster population.

Future studies should aim to improve the confidence and robustness of size at maturity and reproductive potential estimates by expanding and improving data collection, but also develop models and reference points (e.g. egg per recruit) to support the management of the Limfjorden lobster fishery.

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6. The distribution of European lobster (*Homarus gammarus*) in a shallow complex estuarine system

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6.1 Abstract

To better understand habitat utilisation and distribution of the European lobster in the Limfjorden estuary complex a stratified-random field sampling campaign was used to inform models of abundance in relation to two key physical environmental conditions; namely depth and substrate type. Depth has a positive effect on lobster abundance, even in the limited depth ranges of the shallow Limfjorden. Furthermore, stoney habitats were the best habitat relative to sand, mud and mixed substrates. The best habitat association model that could be fit to the snapshot data described these data well but could not reliably predict lobster abundance under novel conditions when tested in random-repeated cross validation. Therefore, no spatial interpolative predictions could be made to produce maps of potential habitat.

6.2 Rationale

To properly manage a living resource, we must understand the conditions that support the resource's growth, survival and reproduction (Bastardie et al., 2021; Crowder & Norse, 2008). A key part of this understanding is knowledge of the physical habitat that support one or more of these three demographic rates (Litvin, Weinstein, Sheaves, & Nagelkerken, 2018; Steneck, Langton, Juanes, Gotceitas, & Lawton, 1997).

While the gold standard is to measure and understand how these demographic rates are modified by the habitat, directly, quantifying growth, survival and reproductive success in the field can be a difficult task in practice (Ciotti et al., in prep). To establish a foundational knowledge of habitat suitability for a species, using abundance as a measure of habitat quality is more practically feasible. While not linking habitat directly to one of the three demographic rates that determine productivity, abundance can provide good insights about habitats and areas of importance, while also informing more efficiently designed future studies with a higher chance of successfully measuring the three demographic rates (Ciotti et al., in prep).

Little is known about the habit and production of European lobster in the Danish Limfjorden system. The Limfjorden, being a shallow, brackish system with relatively large fluctuations in hydrographic conditions such as temperature and oxygen concentration, is an unusual system in which to find European lobster. Lobsters are usually found in deeper, marine waters where the ocean mediates hydrography providing more stable conditions.

In order to understand more about how the lobster population not only survives but supports both commercial and recreational fisheries in this estuarine system, we must investigate the conditions in which lobsters are able to grow, survive and reproduce.

Quantifying growth rates for lobster, and indeed other crustaceans, is difficult due to the punctuated nature of their growth between moults. Furthermore, deducing population growth rates from observations of size (e.g. length / weight) requires sustained monitoring over years and seasons with means of capturing all sizes, not just those sampled by a targeted fishery (Sørdalen, Halvorsen, & Olsen, 2022). Similar to fish otoliths', decapods have bio-archives of growth rates in hard structures that are retained over their lifetime, in spite of the periodic moulting of their carapace. These can be found in the eyestalks, however, the preparation and analyses of these structures are very labour intensive and costly, even more so than fishes' otoliths (Sheridan, Durán, Gil, Pastor, & O'Connor, 2020). Therefore, a properly designed and targeted sampling design should be planned before collecting samples to investigate environmental drivers of lobster growth.

The use of cohort studies to determine mortality/survival is problematic for decapods, again because of the aforementioned moulting making tagging over long term difficult and the punctuated growth that comes with it. Tethering experiments that allow researchers to directly observe instances of predation provide a much more accurate picture of mortality, however, in the field, these studies are labour intensive and demand a foundational amount of knowledge about habitat use to make the experimental design both efficient and likely to provide improved knowledge about the conditions that improve survival (Ellis, 2018).

Of the three demographic rates, reproductive success is perhaps the most difficult to directly measure and observe. This can be measured at different points in the life-history of the lobster; it could be measured by the abundance of eggs/egg carrying females in an area or habitat, however, the production of eggs doesn't necessarily result in successful recruitment of juveniles into the adult population and females carry eggs for extended periods of times, making comparisons more convoluted. Successful reproduction, in a population context, depends on the survival of offspring during the many larval and juvenile stages post-hatch and that these juveniles drift to suitable habitats in time for settlement so that they may grow and survive to reproductive age themselves. Population level genetic studies can identify source-sink relationships between stocks in different areas, but they cannot link individual reproductive success to environmental conditions. The study of these much more complex observational studies should only be planned after a solid understanding of other aspects of the biology is gained.

This leaves us in the position of using abundance to establish the foundational knowledge of how European lobster use the various habitats of the Limfjorden. Knowledge of where most lobsters are can support better spatial management but also provide the understanding of habitat use needed to properly plan and execute future studies focussed on the more direct measures of habitat quality (growth, survival & reproductive success).

The primary aim of this study was to determine the physical environmental variables that drive lobster abundance in the Limfjorden system. The subsequent aim was to apply this understanding to produce interpolated maps of expected lobster distribution, throughout the fjord system. The results from both of these aims may inform spatial management plans, habitat restoration efforts and future research designs.

The remainder of this chapter documents the methods and summarises the results and findings of this analysis. For a more detailed breakdown of the results, including interactive plots and the code used to undertake the analyses, please see the accompanying supplementary materials in the form of an html document, to be opened in a web-browser.

6.3 Methods

Lobster abundances in any given location were measured using capture in a series of 7 baited lobster pots (henceforth called a “string”), with a spacing of ~15 m and a total overall length of ~90 m. Sampling was undertaken from a small coastal vessel over a 29-day snapshot, in a single year, during the summer closed period before the autumn fishing season opened (from: 23-07-2020 to 22-08-2020). This period was chosen in an attempt to minimise the impact of the intensive extraction at the beginning of the fishing season.

The spatial extent of the study was limited to those basins of the Limfjorden system west of Aggersund and north of Hvalpsund (Figure 6.1).

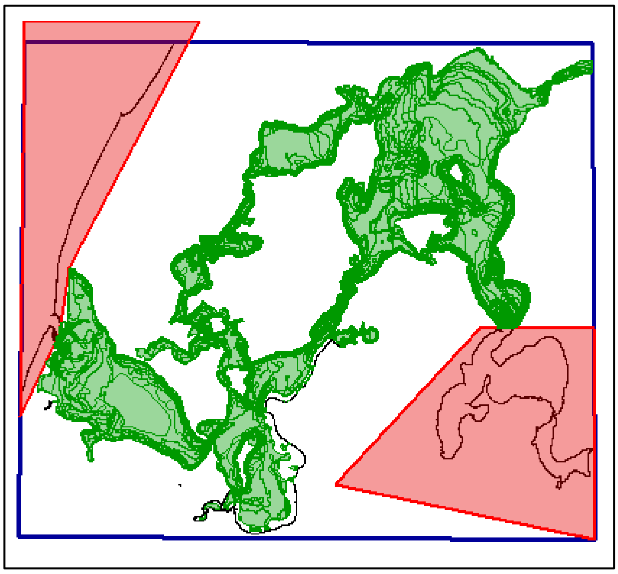

Figure 6.1. Study area, Western Limfjorden. The blue bounding box is the extent that external data was limited to. The red polygons are masks applied to exclude North Sea coastal areas and the area south of Hvalpsund. Green areas are those included for sampling (contours are 1m depths). This figure is projected as "+proj=utm +zone=32 +ellps=GRS80 +units=m +no_defs", with dimensions as metres, therefore axes are not labelled.

Sites were predefined using a random selection of sites across a combination of two strata; depth and substrate type, as well as maximising spatial variation within strata (function *spsample*, from the package *sp* (Bivand, Pebesma, & Gomez-Rubio, 2013; Pebesma & Bivand, 2005), implemented for R (R Core Team, 2021). Sampling locations were further constrained by the resources available to the sampling campaign. The overall conditions under which site selection was done are summarised in Table 6.1. While the sampling plan was predetermined according to the best available data, final positions were decided at the discretion of the field sampling crew, *in situ*. This was done to ensure a best match of the stratification criteria assigned to each site, instead of relying entirely on the provided GPS positions. Furthermore, after planning the sites, discussions with local fishers encouraged us to increase the soak time to a target of 72 hours. More pots were available than already planned and so the target number of sites was retained with the increased soak times.

The 100 sites in this sampling plan were relatively evenly distributed across the levels of each stratification variable (depth categories: 2-3m, 3-4m, 4-5m, 5-6m, 6+m and substrate categories: Mud, sand, stones, mixed). However, some combinations of these strata were not well represented in space (e.g. mixed substrates at six metres and greater depth), and therefore had fewer stations allocated to them, to allow for a better spatial distribution of sampling sites.

Table 6.1. Description and sources of parameters used to define survey design.

Parameter	Description	Source
Area of interest	Limfjorden from the North Sea entrance to Aggersund and Hvalpsund	Work package meeting discussion
Depth	Five categories of one metre depth, from one to six metres deep	General biology of Limfjorden hummer, fishermen descriptions of catches, and "Danish waters in a 500m grid DTM" data accessed via https://portal.emodnet-bathymetry.eu
Substrate	Folk 7-class substrate classification	GEUS: DK-001 data layer accessed via https://www.wemodnet-geology.eu/
Number of pots/traps	84 individual pots/traps	Work package meeting discussion
Number of pots/traps to a string/site	Seven	Work package meeting discussion (between 6 and 10)
Number of sampling days	29	Work package meeting discussion
Pots/traps soak time	72 hours	Work package meeting discussion

All lobster caught were measured to the nearest mm (carapace length; CL), sexed, inspected for eggs, and inspected for damage (e.g. missing claws), before being returned to the sea at the same location.

Lobster abundance, per string, was used as the response variable in building appropriate generalised linear (mixed) models, GL(M)Ms (Brooks et al., 2017). The physical attributes of the environment that were observed / recorded at each site using an underwater camera were used as explanatory variables in the conditional model, these were depth and substrate type. Furthermore, a spatially explicitly model was built using the latitude and longitude of each site to account for spatial autocorrelation. The models also used the log of soak time as an offset to account for the varying effort in how long the pots were actively fishing. This offset was logged, to create a 1:1 relationship between the lobster abundance and the effort, whereas the relationship between the abundance and environmental variables was linked through the natural linking function (log) for the probability distributions that were employed. A representation of the full model with all explanatory variables, including spatial autocorrelation is given below:

$$Abundance \overset{nbinom}{\sim} Depth + Substrate + \exp(lat, lon) + offset(\log{(soaktime)})$$

Where Abundance is the number of lobsters caught in any given retrieval of a string of pots. The tilde (~) represents the link function for the negative binomial distribution. On the right side of the equation, Depth is a continuous explanatory variable, Substrate is a categorical explanatory fixed effect, “exp(lat, lon)” represents the notation describing the spatial autocorrelation term and “log(soaktime)” is the offset which is modelled linearly with the response, not included in the conditional model linked through the non-normal probability distribution.

The best probability distribution was determined by fitting the full model using different probability distributions and investigating the standardised residuals (Hartig, 2018) for expected fits and matches to expected quantiles. The range of probability distributions investigated was limited to those known to approximate ecological count data, namely: Poisson, negative binomial (with both linearly and quadratically linked dispersion). Extensions of Poisson were also investigated, such as zero-inflated Poisson and so called "hurdle models", where a presence/absence is first modelled as a binomial process and combined with a truncated Poisson distribution to model abundances, given presence from the first process.

After selecting the most appropriate probability distribution for the response, the most parsimonious model was selected via dropping different explanatory variables from the model seeking the lowest AICc. Where AICc values were within a limit of about six (Richards, 2008), the total degrees of freedom used in the model was then minimised.

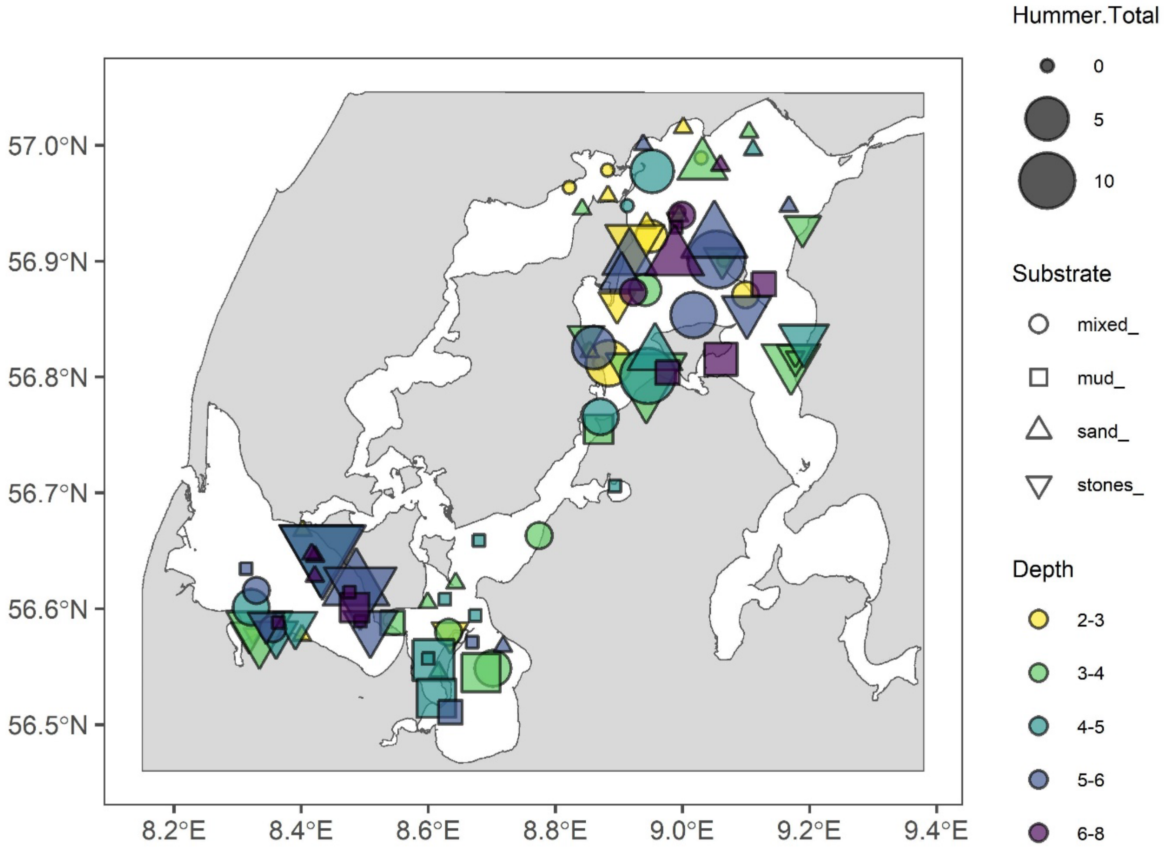

Figure 6.2. Number of lobsters per string of pots (size) at sites (position) of varying substrate (shape) and depth (colour).

Selected models were put through a procedure called repeated random sub-sampling cross validation, whereby the full data set is divided into a training dataset (90%) and a test dataset (10%), before re-estimating the parameters of the model using only the training dataset. The response is then predicted for the test dataset (which the re-fit model is naive to) and metrics of how well the model was able to predict the observations are made. This process of randomly splitting, retraining the model and predicting on the test dataset is repeated 500 times to get a range of values for the metrics of model predictive ability. These metrics were bias, mean absolute error (MAE), root mean-squared error (RMSE), and the correlation coefficient (R^2). Models with generally low bias, MAE, RMSE and high R^2 are better at predicting abundances where no observations have been made.

6.4 Results

Data collected

Ninety-seven stations were sampled (Figure 6.2) across eighteen strata (Supp. Fig 1). No stations of mud at two-three metres depth, nor stones at six plus metres depth were found nor sampled.

String fishing times were approximately normally distributed around the target soak time of 72 hours, except for one string that was collected after only two days (~49 hours), due to logistical restrictions (Figure 6.3).

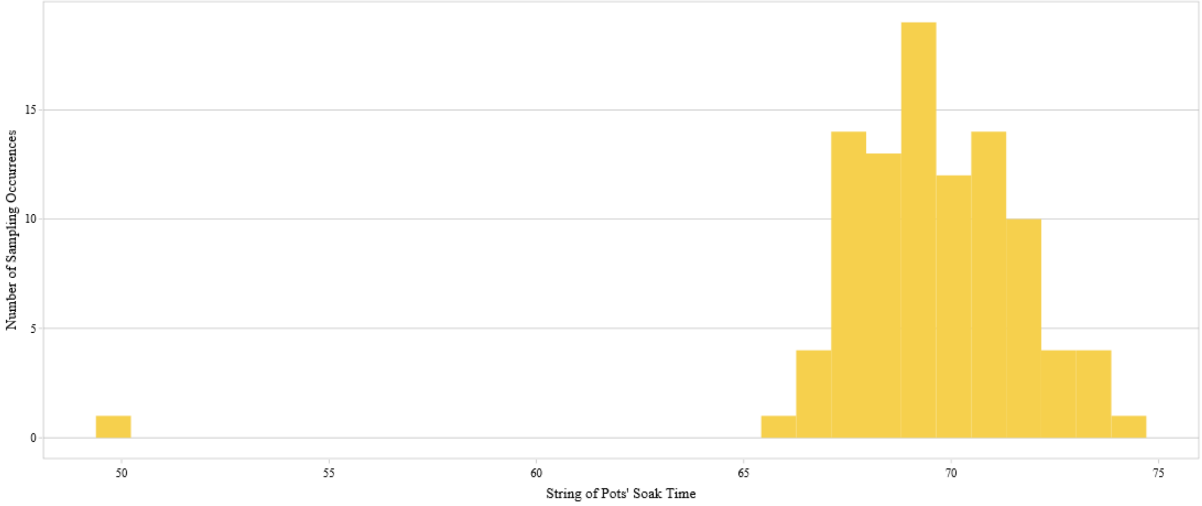

Figure 6.3. Frequency distribution of pot/string soak times (time from deployment to retrieval).

The number of lobsters per site appears to follow a Poisson type distribution, which is to be expected for count/abundance data for ecology studies (Figure 6.4).

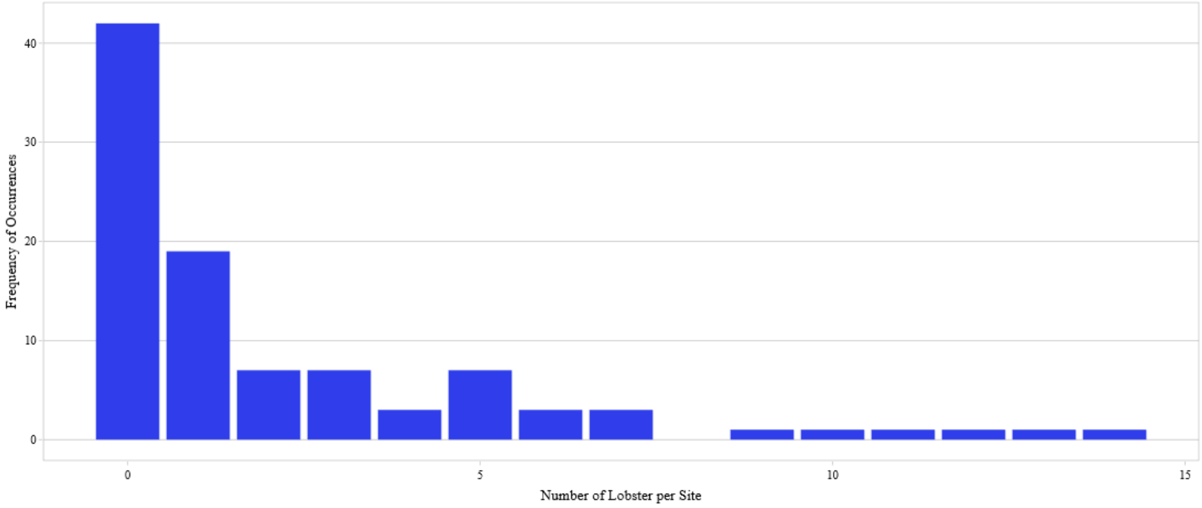

Figure 6.4. Frequency distribution of lobster caught per site (not adjusted for soak time).

Distribution modelling

The probability distribution giving the best residuals was the negative binomial model with dispersion linked linearly with the mean ("nbinom1", in *glmmTMB*) (Figure 6.5). While there appears to be some over-dispersion illustrated by the curve in the residuals of the QQ-plot, this was not found to be significant in the test for dispersion (p=0.84). Furthermore, there was no indication that the underlying data do not come from a negative binomial distribution (KS-test: p=0.23).

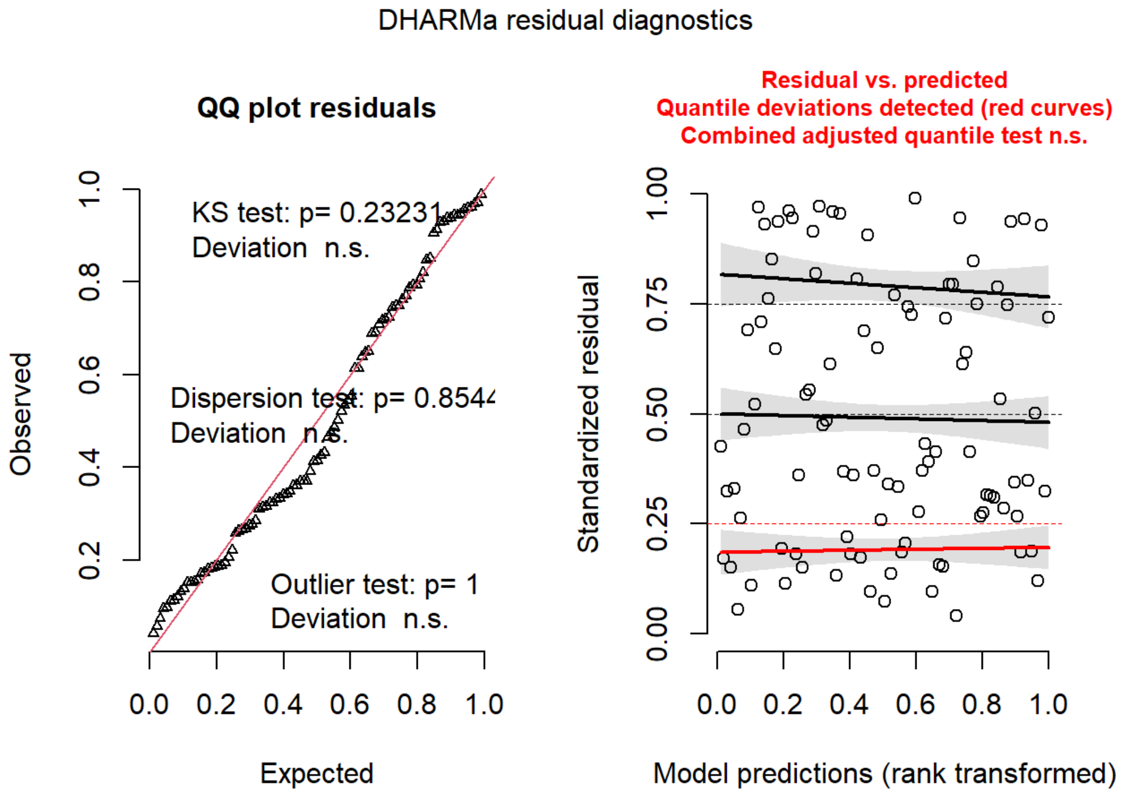

Figure 6.5. QQ-plot and standardised residual distributions for the model of lobster abundance according to depth and substrate, without spatial autocorrelation term.

According to model selection, the inclusion of a spatial autocorrelation term greatly increased the degrees of freedom used in the model, without a great improvement in the model fit to the data. This resulted in higher AICc values indicating less parsimony between the model and the underlying data, compared to the non-spatially explicit model. Furthermore, the removal of either depth or substrate as explanatory variables significantly reduced the model's fit to the data. Therefore, the best model retained from model selection was one where lobster abundance (offset by soak time) was linked to depth and substrate according to a negative binomial response distribution, and without explicitly modelling spatial autocorrelation. This can be represented as below:

$$Abundance \overset{nbinom}{\sim} Depth + Substrate + offset(\log(soaktime))$$

Where the terms are described above in the methods. Increasing depth appears to have a positive effect on lobster abundance. Stones was the only substrate to have a positive effect on lobster abundance. Mud and sand both had weak negative effects, while mixed sediments had the largest negative effect on lobster abundance (Table 6.2). Due to the link function, only the relative values (larger/smaller, positive/negative) of the estimated parameters should be compared as the magnitudes are reported on the scale of the conditional model, not transformed through the link function to the scale of the response (i.e. direct effect on abundances).

Table 6.2. Estimated effect sizes of physical environmental attributes on lobster abundance. Note, magnitudes of the effect sizes and errors are on the scale of the conditional model and therefore do not relate directly to the abundance. Interpret these values relative to one another according to positive/negative effects and larger/smaller effects.

Environmental Variable	Estimated Effect	Std. Error
Substrate (mixed_)	-4.61215	0.49177
Substrate (mud_)	-1.07458	0.4037
Substrate (sand_)	-1.22674	0.42159
Substrate (stones_)	0.42673	0.2892
Depth.Mean	0.31293	0.09538

Repeated random sub-sample cross-validation was undertaken for the selected model and returned overall poor results for the selected metrics.

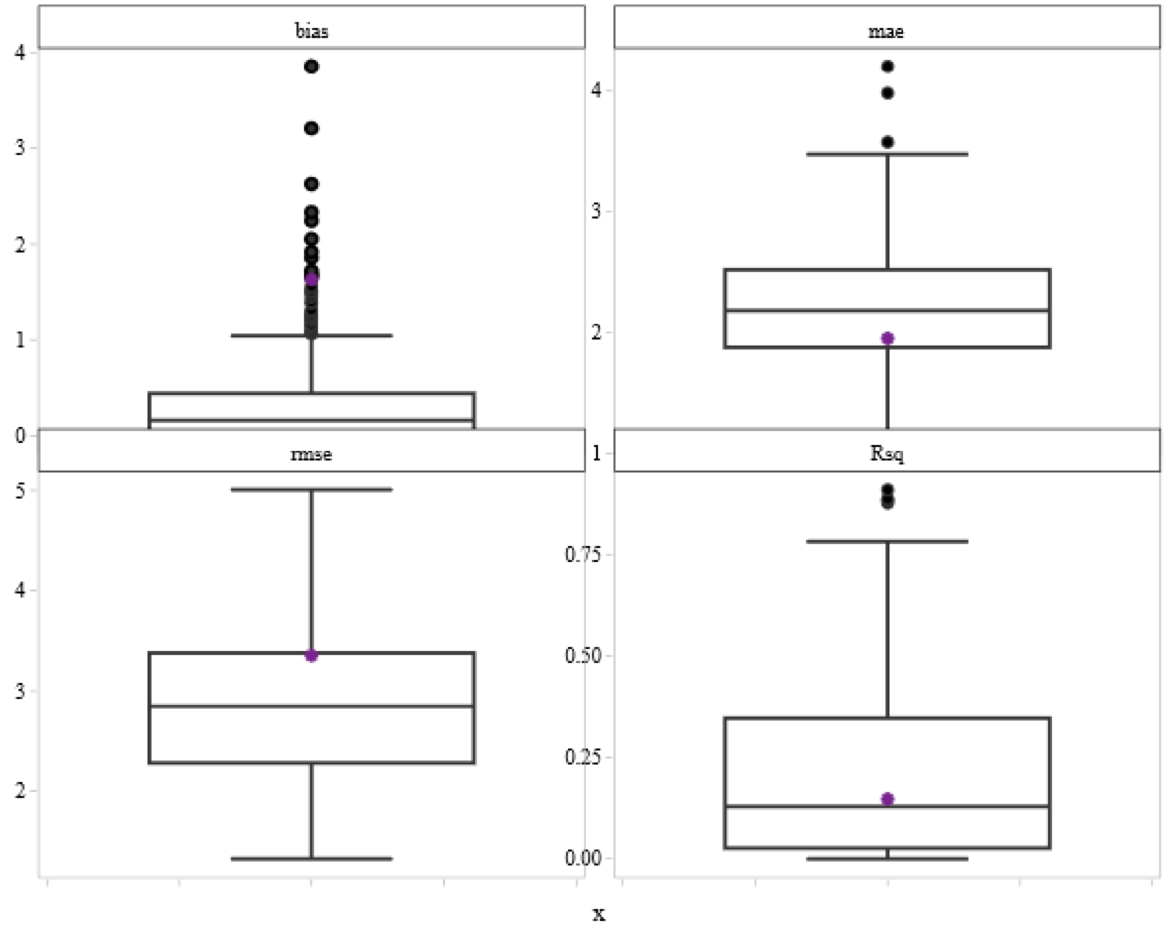

Figure 6.6. Box plots showing the distribution of performance metrics for the simple negative binomial GLM of lobster abundance explained by depth and substrate. The cross validation compares predicted values vs observed values for a series (500) of randomly divided test and training data sets (naive predicting). Boxes represent the distribution of the metrics across the iterations, purple dots represent the value of the statistic for the full model predicting on itself (non-naive predicting).

6.5 Discussion and conclusions

Our selected and best fitting model describes the data we have well and provides insights to the effects of depth and substrate on lobster abundance, which achieves our primary aim. However, our validation attempts show that this model is not reliable for predicting abundances in conditions observed in the training dataset and hence we cannot reasonably produce maps of expected lobster distribution in the Limfjorden, failing our second aim. Below we discuss the insights that our model provides, as well as detailing some of the limitations of our approach and how they can be overcome in future work.

We found that increasing depth has a positive effect on lobster abundance, even over the relatively narrow depth ranges found in the Limfjorden. This indicates that the relatively few deeper areas of this system routinely have more lobsters than the more abundant shallower areas, when all other conditions are equal.

Of the substrate categories investigated, only the “stones” category had a positive influence on the abundance of lobsters. This indicates that relative to the other soft bottom types and the “mixed” category where stones were few, the structural complexity of stone reefs probably offers some benefit to lobsters. This could be in the form of refuge from predation, or increased abundance of prey items such as other lobsters, crabs, while bivalves will be more abundant in soft and mixed substrates. While a preference for structurally complex rocky bottoms or reefs isn’t entirely surprising, what is surprising is that the model estimates that sand and mud areas would consistently provide much lower relative abundances than the stoney habitat, in spite of the fact that this species is known to create burrows in muddy habitats, where pre-existing three-dimensional complexity is not found.

In terms of the dataset, the survey has fairly good coverage according to both the selected levels of stratification (depth and substrate) and the spatial coverage of the fjord system. However, it is severely limited in two ways: the first is that the environmental observations were limited to depth and substrate, limiting the investigation of any other potential drivers of distribution, such as temperature, salinity, water clarity, or oxygen saturation. The second limitation is the fact that observations only represent a snapshot of one season in one year. While this is a good starting point and represents an extremely efficient use of the resources that were available for this work-package of this relatively small project, information on abundances from across different seasons and over multiple years would increase the environmental variability and improve such modelling approaches by providing information in data-spaces where there are currently no observations.

The inclusion of a spatial autocorrelation term did not improve the fit and hence, nor did it improve its parsimony with regards to fit vs. parameter trade off. This effect would probably have more influence if there were more sites and especially if there was a multiannual dataset where sites close to one another were sampled across years, as well. There are many tools that account for spatial-autocorrelation but the approach taken for GLMMs, used here, is somewhat limited. It does not account for land masses between basins and will weight sites close together on opposite sides of a peninsula or island as being more correlated than sites further apart but along the same coast of the same basin. This inability to account for the complex coastal features in the Limfjorden is probably why including the spatial autocorrelation co-variance did not improve our model, in this case.

To create better models of lobster distribution and habitat suitability, further data need to be collected. A targeted survey investigating multiple seasons across multiple years would improve the variation in the explanatory variables and help to detect the effect of this increased environmental variation. The increase in sample size (number of observations) that such an expanded survey would provide, would also allow the use of more flexible modelling tools such as General Additive Models (GAMs).

The application of GAMs would allow for more complex relationships between environmental variables and habitat suitability. For example, if there is an optimum depth not just that deeper is always better, GAMs can accommodate a relationship that changes direction like this, while GLMMs expect a monotonic relationship. This would also facilitate the inclusion of more environmental parameters, which would better describe the habitat in any particular location. Additional variables that could be incorporated, if they were observed in the survey may include physical contexts such as temperature, salinity, oxygen concentration, exposure, and turbidity, as well as biological variables such as potential prey and predator abundance. The observation and subsequent incorporation into models would allow for variation in lobster abundance to be further partitioned out and explained, improving model predictive capabilities.

While habitat association models (those that predict abundance) can be used to find where lobsters happen to be more plentiful, they are not the best indicator for habitat quality. Demographic rates such as growth, survival, reproductive success and life-history stage connectivity are truer proxies for habitat quality. Should further work on identifying and quantifying lobster habitat be undertaken, we would recommend attempting to measure one or more of these demographic rates in parallel to abundance.

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7. European lobster (*Homarus gammarus*) movement and home range in the Limfjorden

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7.1 Rationale

The European lobster (*Homarus gammarus*) population in the Limfjorden underwent a recent expansion with landings increasing significantly in the last 15 years after an almost complete absence from the estuary for 40 years from the mid-1960s, reflecting a return similar to early 20th century historical abundance levels (Chapter 2, this report; Fiskeristyrelsen). The Limfjorden constitutes a peculiar habitat for European lobsters in that it is a relatively large (ca. 15,000 km^2), very shallow estuary (mean depth 4.8 m, with only a small area deeper than 8 m), dominated by muddy and sandy bottom substrate with large boulders or reefs almost absent. The estuary is a microtidal (amplitude ca. 0.1 to 0.2 m) enclosed system with only two connections to the North Sea in the west and the Kattegat in the east, with significant salinity gradients (Hofmeister et al., 2009). In contrast, the common habitats of the European lobster occur in rocky boulder and sandy areas of open coast and bays in the northeast Atlantic continental shelf from Morocco and the Mediterranean to Norway, usually between 20 to 60 m deep but reaching down to 150 m (e.g. Cooper and Uzmann, 1980; Cobb & Castro, 2006; Whale et al., 2013).

Movement and activity patterns of European lobsters show considerable variation among individuals, which result from a complex influence of daily and seasonal cycles together with multiple factors, such as habitat, density, size, sex and competition for food, shelter and mating (e.g. Smith et al., 1998, 1999, 2001; Hoskins et al., 2009; Moland et al., 2011a, b; Skerrit et al., 2015; Thorbjørsen et al., 2018).

The specific shallow and enclosed conditions of the Limfjorden may influence lobster home range size, movement and migration patterns, possibly limiting or favouring how lobsters forage and move in reaction to unfavourable environmental conditions (e.g. temperature, salinity or oxygen levels). Therefore, the general aim of this study was an assessment of daily and seasonal movement patterns and home range size of lobsters in the Limfjorden, as well as to collect information on potential connection between different areas within the estuary. Two approaches were used: (1) a larger scale mark and recapture study in most of the western and central Limfjorden and (2) a smaller scale acoustic telemetry study at the Livø stone reef and marine protected area (MPA).

7.2 Methods

The study was conducted in the western Limfjorden in northern Denmark (Figure 7.1) and used two approaches: Mark and recapture of lobsters provided information on net travelled distance at larger scales between marking and recapture locations, relying on fishermen for information of recapture date and location over two years between 2020 and 2022. An acoustic telemetry study in and around Livø stone reef and MPA between August 2021 and January 2022 (Figure 7.1) provided information on movement and activity at smaller scales (ca. 6000 by 800 m), such as home range size, diurnal and seasonal patterns, depth, sex, and size related differences in movement.

Tag and recapture

Lobsters were marked on two occasions (Table 7.1): 212 lobsters during a large-scale survey across the western Limfjorden in July and August 2020 and 840 lobsters during two small surveys in and around the Livø stone reef and MPA in Løgstør Bredning in August 2021 (Figure 7.1), as part of another project (Petersen et al., 2022).

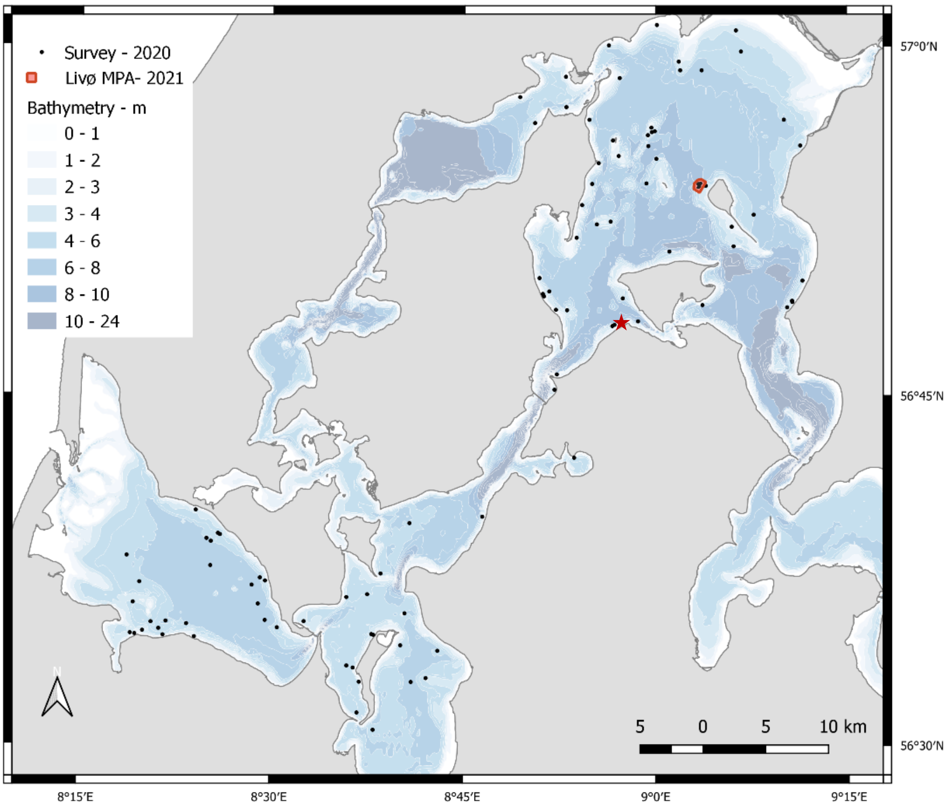

Figure 7.1. Lobster marking locations in the western Limfjorden survey in 2020 (black dots) and in the Livø stone reef and MPA in 2021 (red mark). The red star marks the location of an acoustic telemetry detection range test in Grynderup (see text for further details).

Upon capture lobsters were measured, weighed, sexed and the ovigerous status of females assessed. Lobsters were tagged with individually numbered T-bar tags (Hallprint Pty., Holden Hill, Australia; TBA standard anchor T-bar tags) in the dorsal musculature between the cephalothorax and abdomen using a standard tag applicator (Mark III Pistol Grip Swiftach Tool Avery Dennison, USA). Such approach was used successfully in other studies (e.g. Smith et al. 2001) and protects the tags from wear and damage, which can be retained through ecdysis (Jensen et al., 1994). A V-notch was also made in a tail uropod (Figure 7.2). Lobsters were released at their capture location. The shortest straight line travel distances between mark and recapture locations were determined for individual lobsters, when necessary breaking travel path into multiple segments to avoid emerged land.

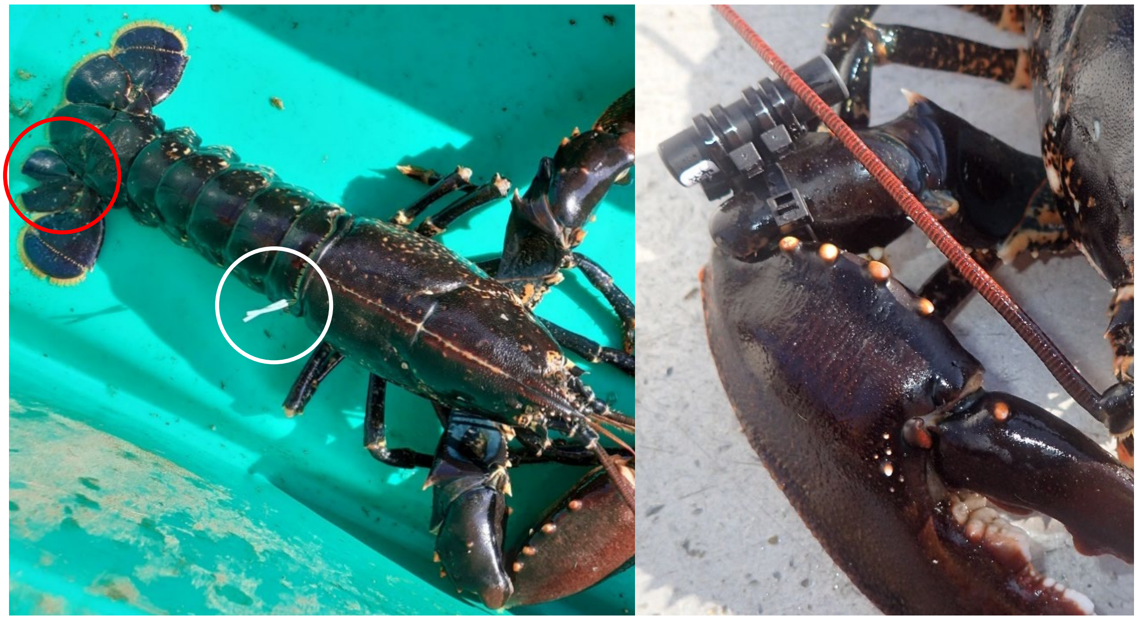

Figure 7.2. Lobsters marked with a T-bar tag (white circle) and a V-notch (red circle) in a tail uropod (left), and an acoustic transmitter (right).

Table 7.1. Summary of marked and recaptured male and female lobster carapace length (CL, mm) and distance (m) travelled.

Marked						Recaptured								
		Carapace Length							Carapace Length			Distance		
Survey		N	Mean	Min.	Max.		N	%	Mean	Min.	Max.	Mean	Min.	Max.
Limfjorden – 2020						*2020*								
	F	98	87	51	121	F	0	0						
	M	114	81	51	24	M	2	1.8	95	90	100	1,118	1,015	1,220
						2021								
						F	1	1.0	87			4,413		
						M	0	0						
						2022								
						F	1	1.0	83			512		
						M	1	0.9	86			12,000		
Livø – 2021														
	F	286	84	47	117	F	11	3.8	86	70	96	644	2.4	1,586
	M	554	90	47	132	M	66	11.9	100	67	126	284	4.4	1,263
						2022								
						F	2	0.7	71	70	72	285	165	405
						M	8	1.4	90	68	120	491	130	1,257

Telemetry

The acoustic telemetry study was conducted in and around Livø stone reef and MPA over 139 days between August 2021 and January 2022 (Figure 7.1). The Livø MPA is located northwest of Livø Island in the Limfjorden between 3 to 9 m water depth, on an area dominated by hard substrate (Figure 7.3) that previously contained large rocks and stone reefs, which were exploited for stones over the past century (Vedel, 2016). Bottom substrate in the study area is mainly made up of boulders in stone reefs, stones (gravel, cobble), mix of stones with sand and patches of sand, while in the deeper part to the west, mud and sandy mud dominate with some blue mussel beds present (Petersen et al., 2022). The study area provided some protection from fishing due to the MPA, a significant depth range for the Limfjorden (3 to 9 m), a range of bottom substrates from mud and sand to reefs structures offering a variety of shelter sizes (Figure 7.3), and an abundant local lobster population with a large range of sizes for the Limfjorden (Petersen et al., 2022).

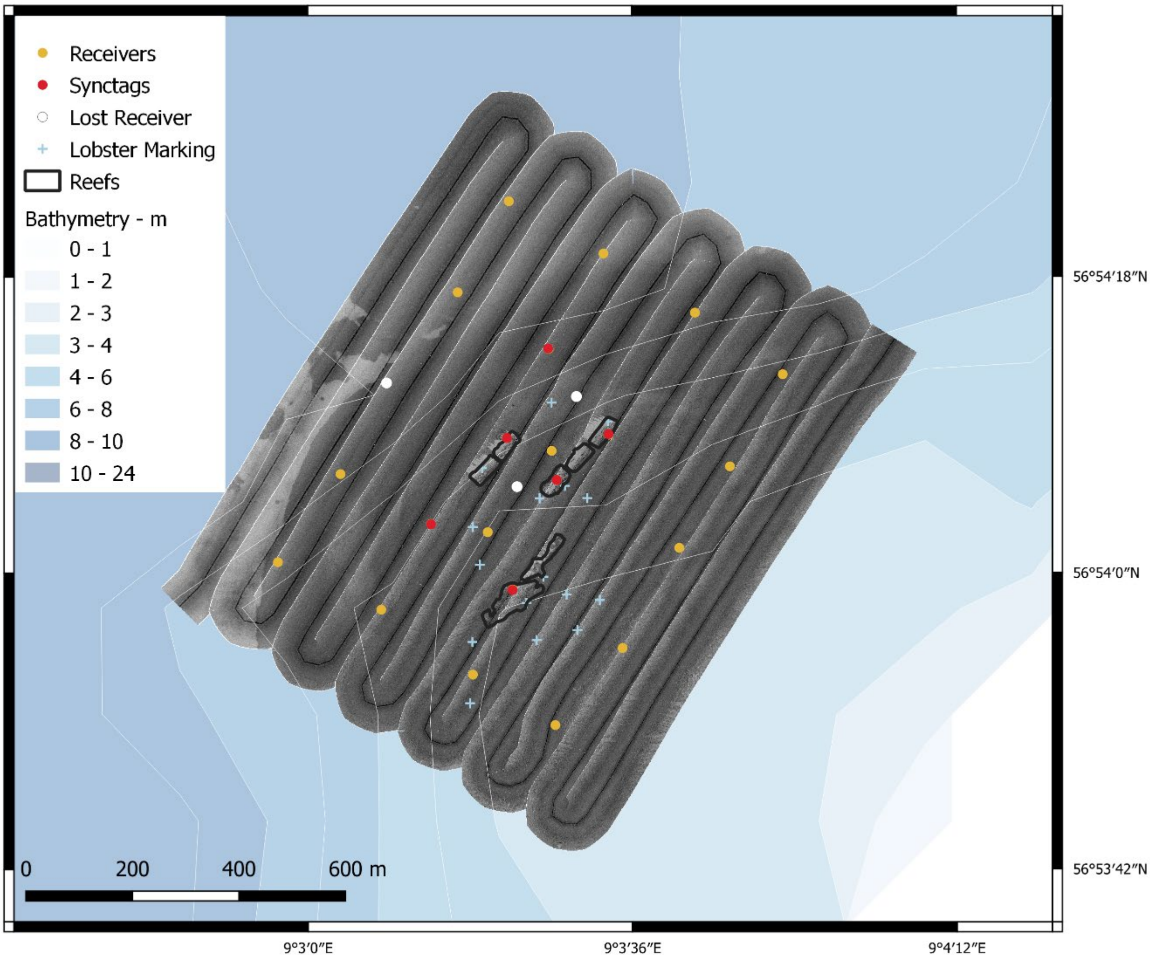

Figure 7.3. Location of the acoustic telemetry receiver array in the Livø stone reef (black lines) and MPA northwest of Livø island in the Limfjorden (see Figure 7.1). The array consists of 24 VR2W acoustic receivers (InnovaSea). Background is a side-scan mosaic identifying the reefs and indicating bottom hardness (inverted scale, hard is dark; soft is lighter). Lighter patches around the reefs are shadow effects of the reefs on the side scan sonar signal, while lighter patches in harder (darker) areas indicate a substrate of sand or mixed sand and stones.

A total of 25 lobsters, 12 females, of which four were ovigerous, and 13 males were tagged on the 20th and 23rd of August 2021 (Table 7.2). Lobsters were caught with baited lobster pots, then measured, weighed, sexed and the ovigerous status of females assessed. Carapace length of female lobsters ranged from 71.5 to 107.3 mm, while carapace length of male lobsters ranged from 83.1 to 109.8 mm (Table 7.1 and Figure 7.4). Carapace length was not significantly different between female and male lobsters (t-test, *p* = 0.208)

Table 7.2. Summary of lobsters marked with acoustic transmitters in the telemetry study, detection, position, distance travelled and home range results. M: Male; F: Female; OF: Ovigerous female; Cl: Carapace length (mm).

ID	CL	Sex	Marked	ID	CL	Sex	Marked
3290	97	F	23/08/2021	3294	90	M	20/08/2021
3292	97	F	20/08/2021	3296	102	M	20/08/2021
3300	72	F	20/08/2021	3298	90	M	23/08/2021
3304	92	OF	23/08/2021	3302	78	M	20/08/2021
3308	88	F	20/08/2021	3306	96	M	23/08/2021
3316	107	OF	20/08/2021	3310	97	M	23/08/2021
3318	95	F	23/08/2021	3312	97	M	20/08/2021
3320	89	OF	20/08/2021	3314	101	M	23/08/2021
3324	88	F	20/08/2021	3322	107	M	20/08/2021
3326	89	F	23/08/2021	3328	83	M	20/08/2021
3334	90	F	20/08/2021	3330	90	M	20/08/2021
3338	91	OF	20/08/2021	3332	105	M	23/08/2021
				3336	110	M	20/08/2021

Lobsters were tagged with an acoustic transmitter placed in a custom holder made with cable ties and then attached to the middle segment (carpus) of one of its claws (Figure 7.2). V9AP-2x coded transmitters with pressure and accelerometer sensors providing information about depth usage and activity were used (9 mm diameter, 31 mm length, 2.8 g in water from InnovaSea, Canada), transmitting at 69 kHz in high power mode at a randomized interval between 130 and 230 seconds. It is possible that acoustic tags were lost due to moulting, or even loss of claws during fighting, but due to the solid hold it is unlikely transmitters were pushed out of the harnesses. Lack of detection reflecting inactivity is only expected when lobsters were inside shelters and lobsters were not expected to be inactive for prolonged periods of time, except a few days during moulting and usually show a diurnal rhythm of activity (e.g. Jury et al., 2005; Whale et al., 2013).

The shallow depths (3 to 9 m) at Livø were expected to reduce the detection probability of transmissions from acoustic tags carried by bottom dwelling animals such as lobsters, due to low angles between tags and receivers, the proximity of the receivers to the surface (noise from waves), as well as acoustic barrier shadowing effects from bathymetry, boulders, and the reefs, which bring the bathymetry up from 5–6.5 m to ca. 3 m depth in the two northernmost units (Figure 7.3).

24 VR2W acoustic receivers (VEMCO/Innova/Sea, USA) were deployed in a 200 m grid array, with four of the receivers placed between the artificial reef units to reduce acoustic shadowing by the reefs (Figure 7.3). Receivers were placed facing down at ca. 1.5 m from the surface on moorings using weights and sub-surface buoys to reduce horizontal and vertical movement. Six V13-1x synchronizing tags (synctags, high power, random delay 540 to 660 seconds) were placed in the moorings of receivers in the inner part of the 200 m grid for determination of variability in detection rates, post-hoc correction of clock drift and large-scale movement of receivers (Figure 7.4). Data were downloaded from the receivers on three occasions in 07/09/2021, 16/11/2021 and 06/01/2022.

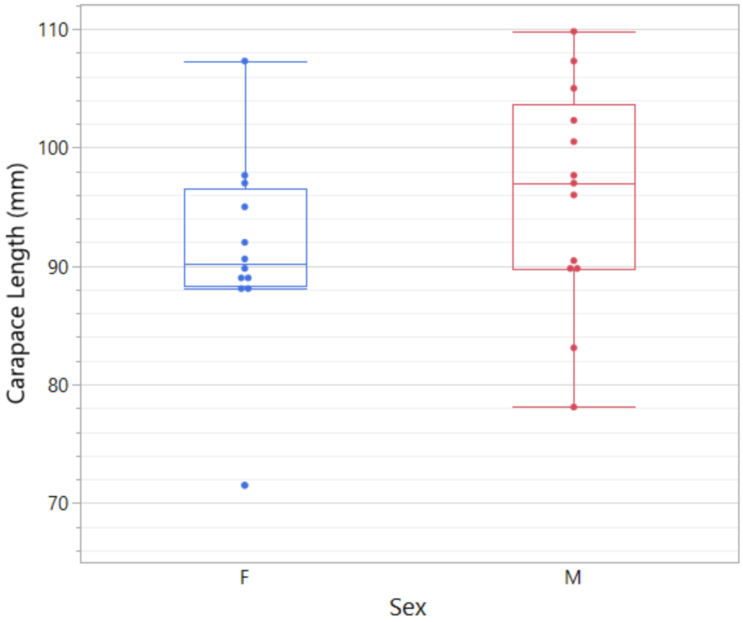

Figure 7.4. Boxplot of carapace length (mm) of marked female and male lobsters with acoustic transmitters. M: Male and F: Female.

Accurate position analysis (YAPS v.1.2.5.9000; Baktoft et al., 2017) processing was split into three separate periods according to data retrieval and redeployment of the receivers, each consisting of a synchronization of the hydrophones and subsequent running of YAPS. Three receivers moved during the second period due to strong storms and new positions were estimated during the synchronization process. Unfortunately, data from three receivers could not be used for YAPS: one receiver at the outer western section of the array was lost during the second period due to a collision with an unknown vessel; data from two receivers did not contain milli-second data needed for YAPS. These three hydrophones were excluded from subsequent analyses including synchronization and YAPS.

Five HOBO temperature loggers (Onset, USA, HOBO 64K Pendant) were placed at the base of 5 moorings at depths of 4, 5, 5.5, 6 and 7 meters and logged temperature every two hours. Water temperature was very similar at all depths reflecting a well-mixed water column (Figure 7.5).

A range-test was conducted in the receiver array area prior to the study and 200m grid spacing was found to be adequate for overlapping detection by multiple receivers to perform accurate position analysis (YAPS). Nevertheless, high wind conditions occurred during the study and out of 139 days, 20 days had mean wind velocity and 95 days had maximum wind velocity (10 minutes average of maximum velocity) higher than 8 m/s (Figure 7.6; DMI). During high wind periods (>8-10 m/s), detection range is expected to decrease significantly lowering probability of transmission detection and position fixes, creating periods of receiver “deafness” of up to a few days during which lobsters could move undetected including away from the receiver array and study site. In a separate study at another location in the Limfjorden site (Grynderup) with similar hydrophones, transmitter tags, depth range and bottom substrate, although without stone reefs, at winds higher than 7-8 m/s detection range when 50% of transmissions were undetected was 200 m (unpublished, Freitas S.F.).

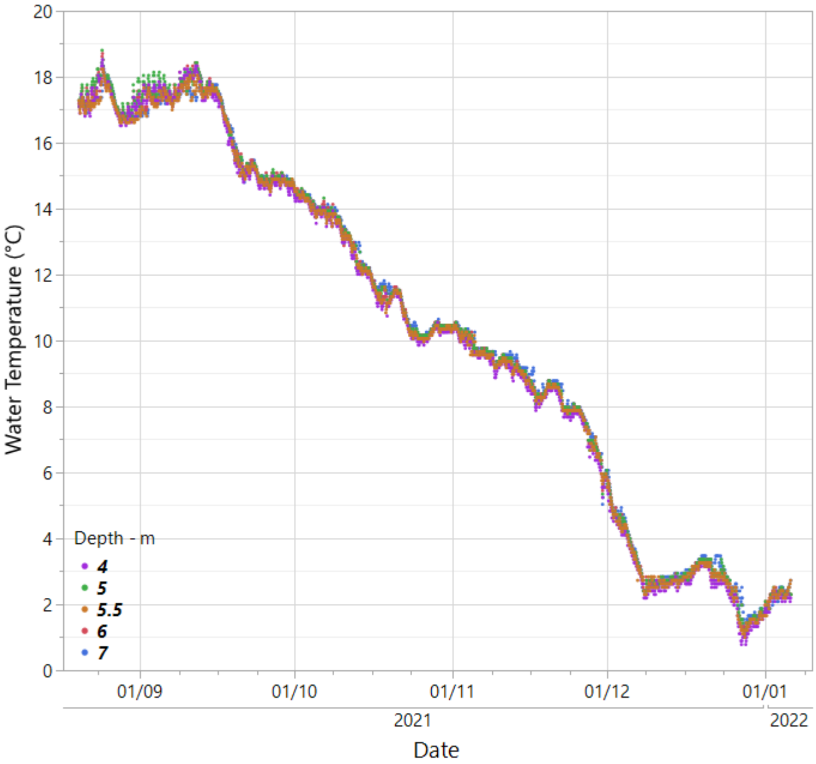

Figure 7.5. Water temperature during the study from HOBO loggers placed on the mooring anchors of five receivers at 5 depths (4-7 m).

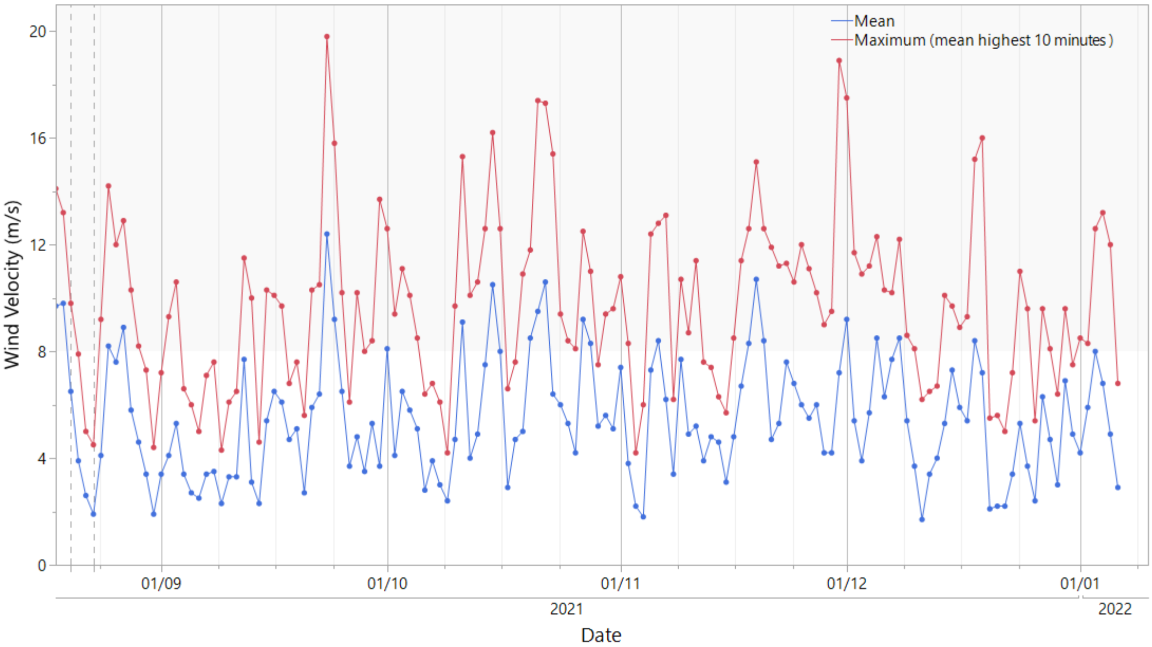

Figure 7.6. Mean and maximum (mean of highest 10 minutes) wind velocity in Morsø (data from DMI). Shading marks wind velocity higher than 8 m/s. Vertical dotted lines mark the beginning of the study.

7.3 Results

Mark-recapture

In total, 92 lobsters or 8.7% out of 1,052 tagged lobsters were recaptured, mainly in the same year and following year after tagging with only two lobsters recaptured after two years. Most lobsters were recaptured within 300-400 m from tagging location even after one year (Figure 7.7). Only two lobsters were recaptured in a different basin than the one they were marked and showed the longest net travelled distances of ca. 4,400 and 12,000 m after one and two years (Figures 7.7 and 7.8).

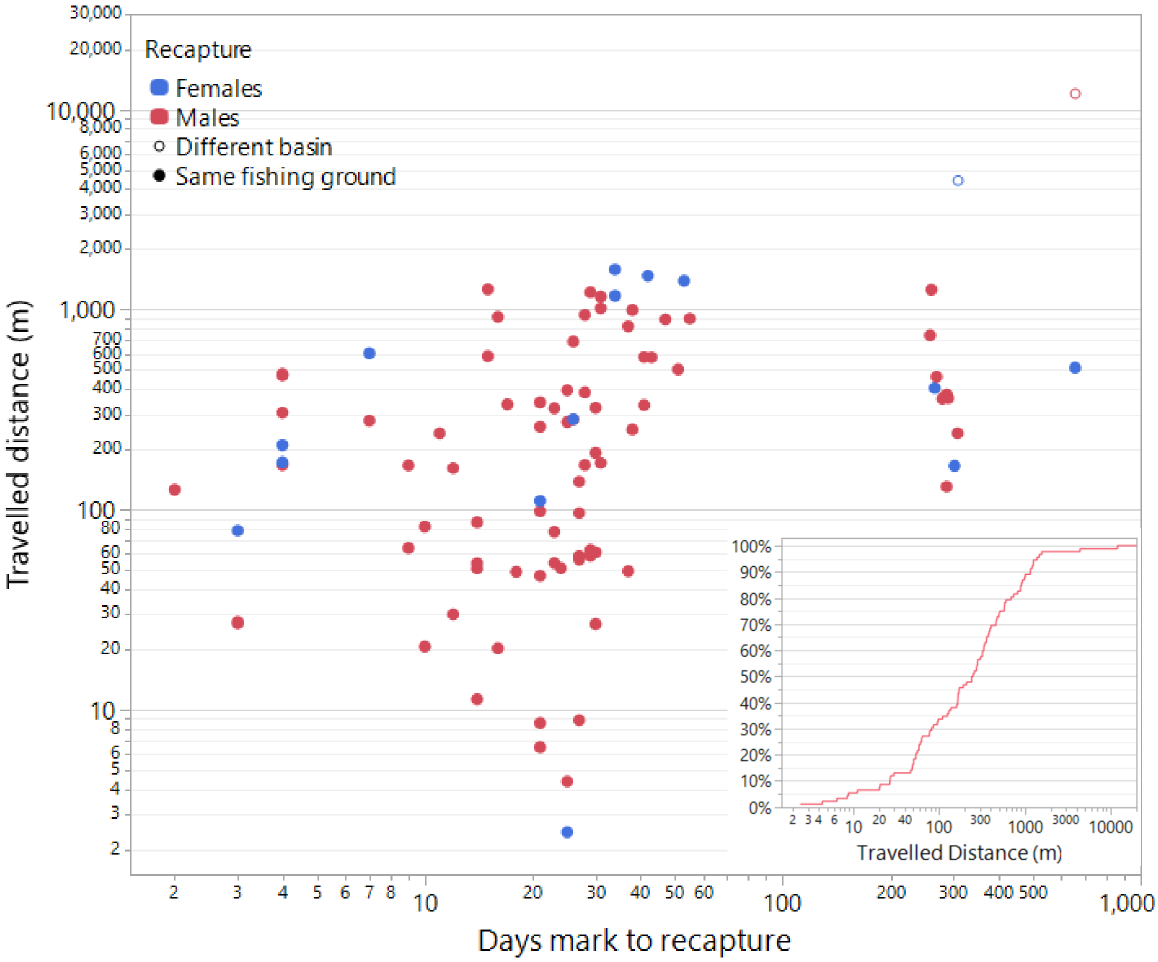

Figure 7.7. Travelled distance against days between mark and recapture of female (blue, *n* = 15) and male (red, *n* = 77) lobsters. Lobsters were mainly recaptured in the same fishing ground (dot) with only two lobsters recaptured in a different basin of the Limfjorden (circle). Inset is cumulative frequency distribution of travelled distance between mark and recapture. Note logarithmic scales.

Net travelled distance averaged 355 ±46 m (SE, n = 79) for lobsters recaptured in the same year of marking and 450 ±105 m (SE, n = 10) for lobsters recaptured after one year, excluding the lobster that travelled ca. 4,400 m (Figure 7.7). Net travelled distance was longer for lobsters recaptured after one year than for lobsters recaptured in the same year of marking (Box-Cox transformed, ANOVA Welch's-Test, F(1,17) = 6.059, *p* = 0.0246). Only two lobsters were recaptured after two years, travelling 512 and ca.12,000 m (Figure 7.7).

Distance travelled was similar between female and male lobsters (Box-Cox transformed, ANOVA, F(1,77) = 2.903, *p* = 0.0925) for lobsters recaptured in the same year of marking (Figure 7.9). The small sample size did not allow to separate analysis per sex for lobsters recaptured one year after marking (females: N = 2 and males: N = 8).

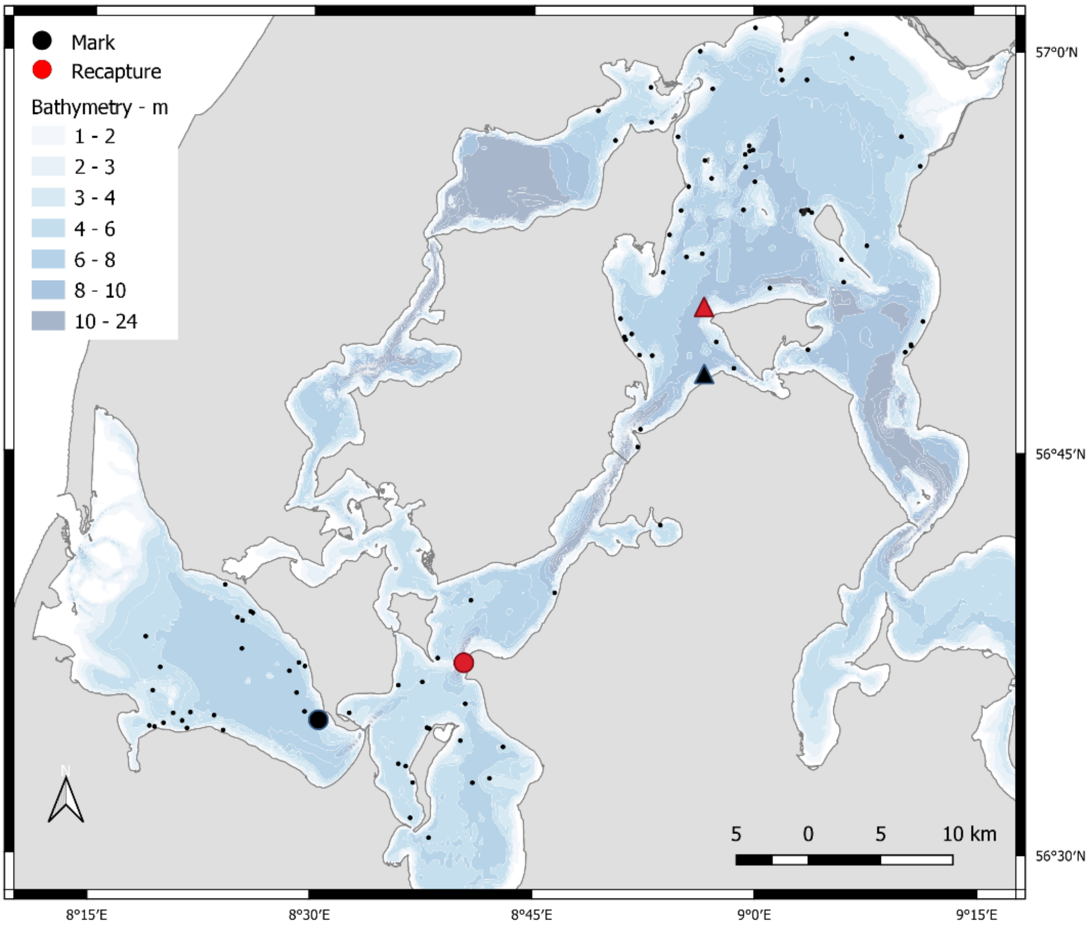

Figure 7.8. Mark (black) and recapture (red) locations of the two lobsters with longest travelled distances in ca. one year (triangles) and two years (circles).

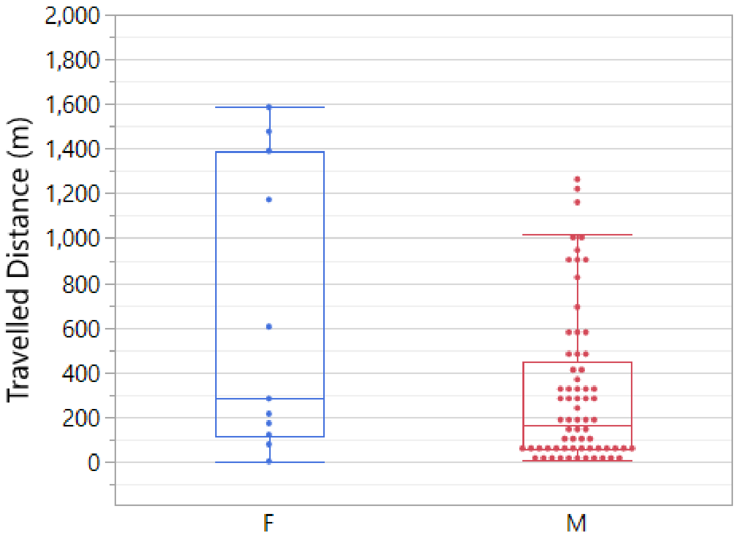

Figure 7.9. Boxplot of travelled distance by female and male lobsters recaptured in the same year of marking at Livø MPA in 2021. Travelled distance was not significantly different according to sex (Box-Cox transformed, ANOVA F(1,77) = 2.903, *p* = 0.0925). M: Male and F: Female.

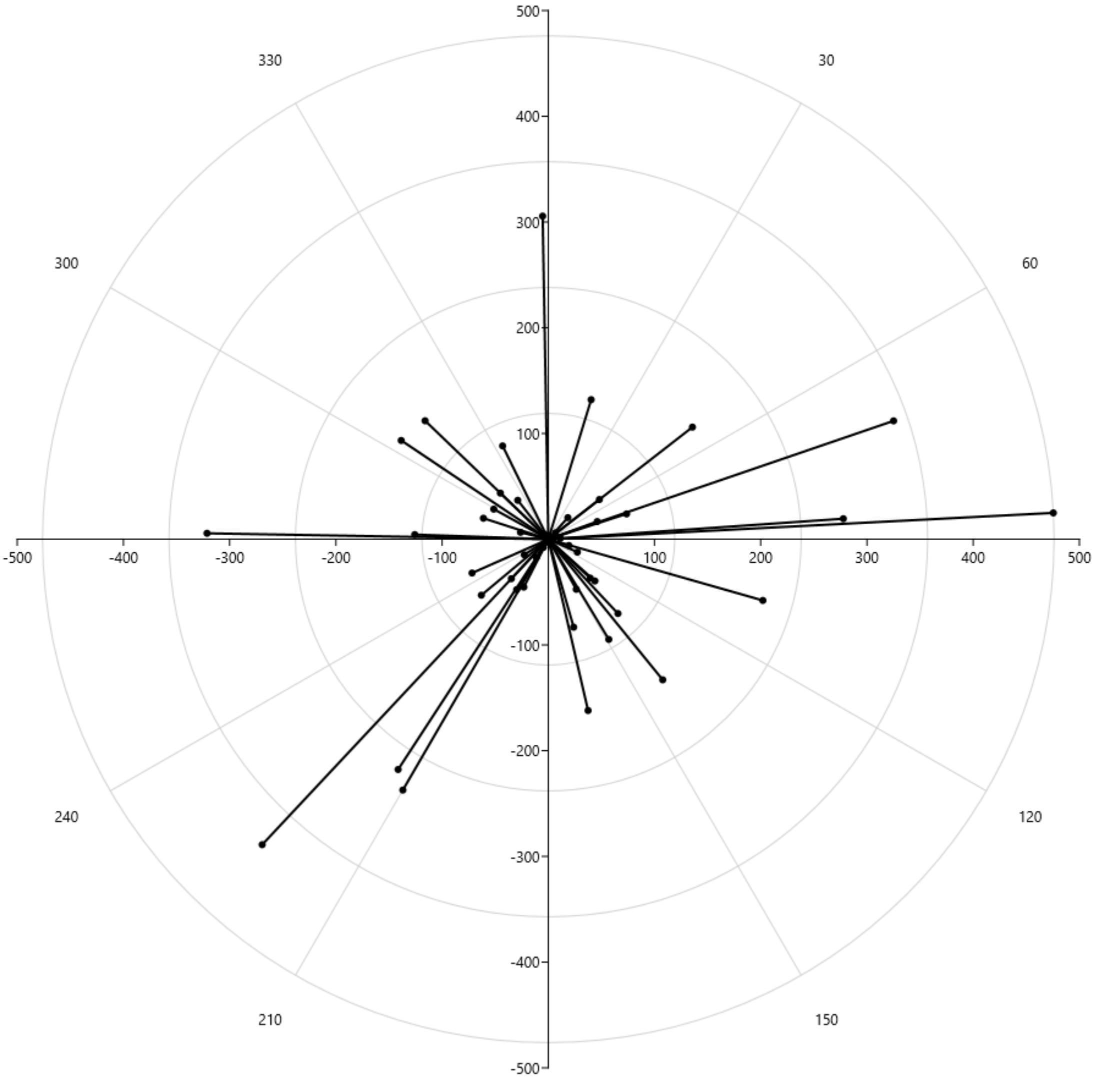

Figure 7.10. Polar plot of travelled distance (m) versus cardinal direction (degrees) of lobsters marked and recaptured over four weeks during two surveys in and around the Livø stone reefs and MPA (Petersen et al., 2022).

In two short-term surveys (over 4 weeks) of the same fishing ground, Livø stone reefs and MPA (Petersen et al., 2022), distance and direction travelled by lobsters were unrelated (Figure 7.10; Pearson $r^2 < 0.0001$, $p = 0.960$, N = 47) and thus lobsters showed no preference for along or across shore movement. However, distance travelled was significantly albeit weekly correlated with depth at marking sites, suggesting lobster travelled farther when deeper (Pearson $r^2 = 0.235$, $p = 0.0006$, N = 47). Small sample size did not allow to assess differences in travelled distance between sexes (females: N = 5 and males: N = 42).

Telemetry

Data overview

All 25 tagged lobsters were detected, and valid position fixes obtained at or just after the start of the study, although the number and continuity of detections and position fixes were highly variable during the study with several tagged lobsters showing long periods with few or no detections or few and no position fixes often followed by further detections and position fixes.

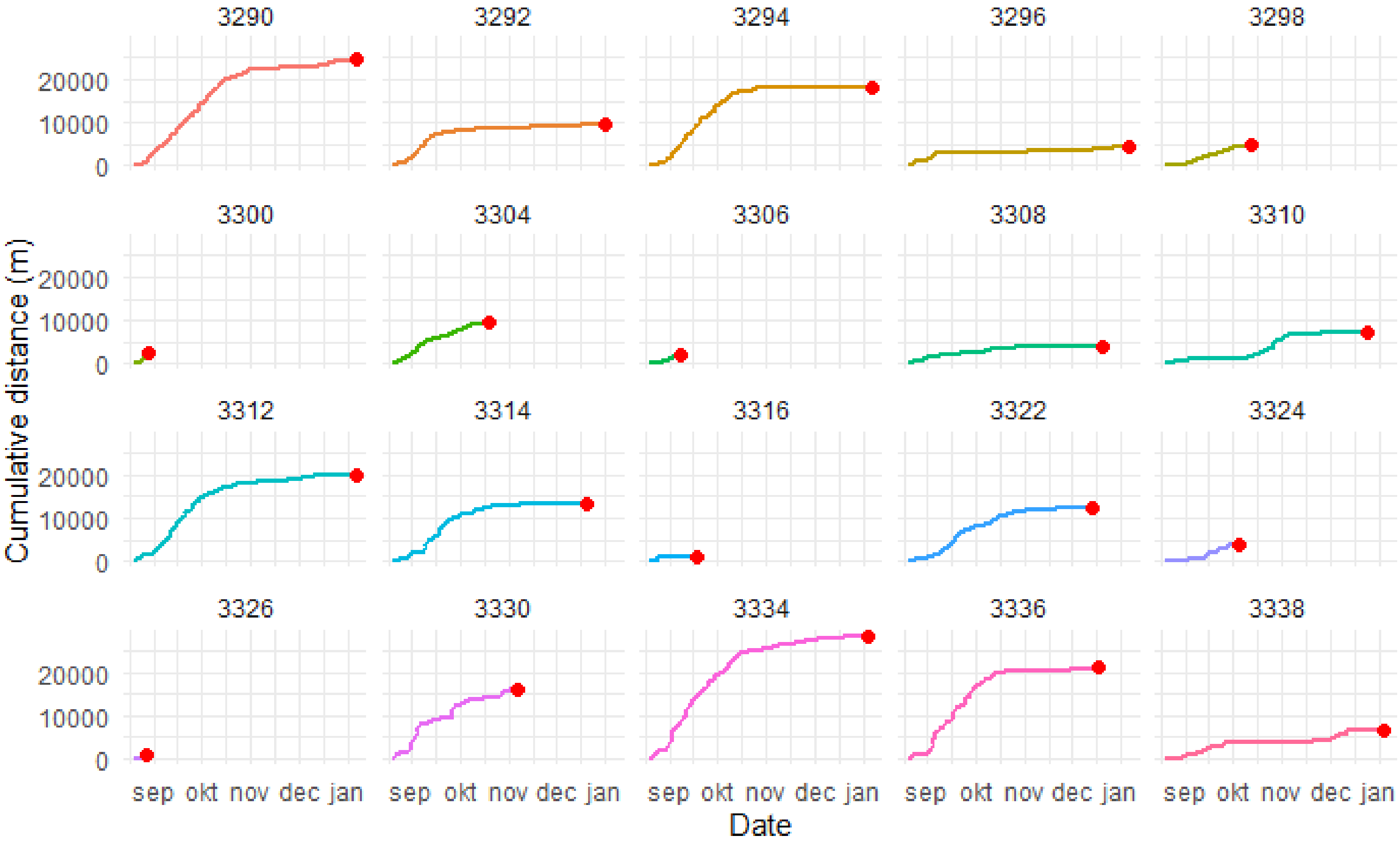

Figure 7.11. Cumulative distance moved by each tagged lobster until last detection. Tag ID as in Table 7.2. Periods of no movement do not necessarily reflect loss of or inactivity of tags but can reflect lack of detection (e.g. moving out of the receiver array detection) or the ability to obtain a position fix (e.g. not detected by enough receivers).

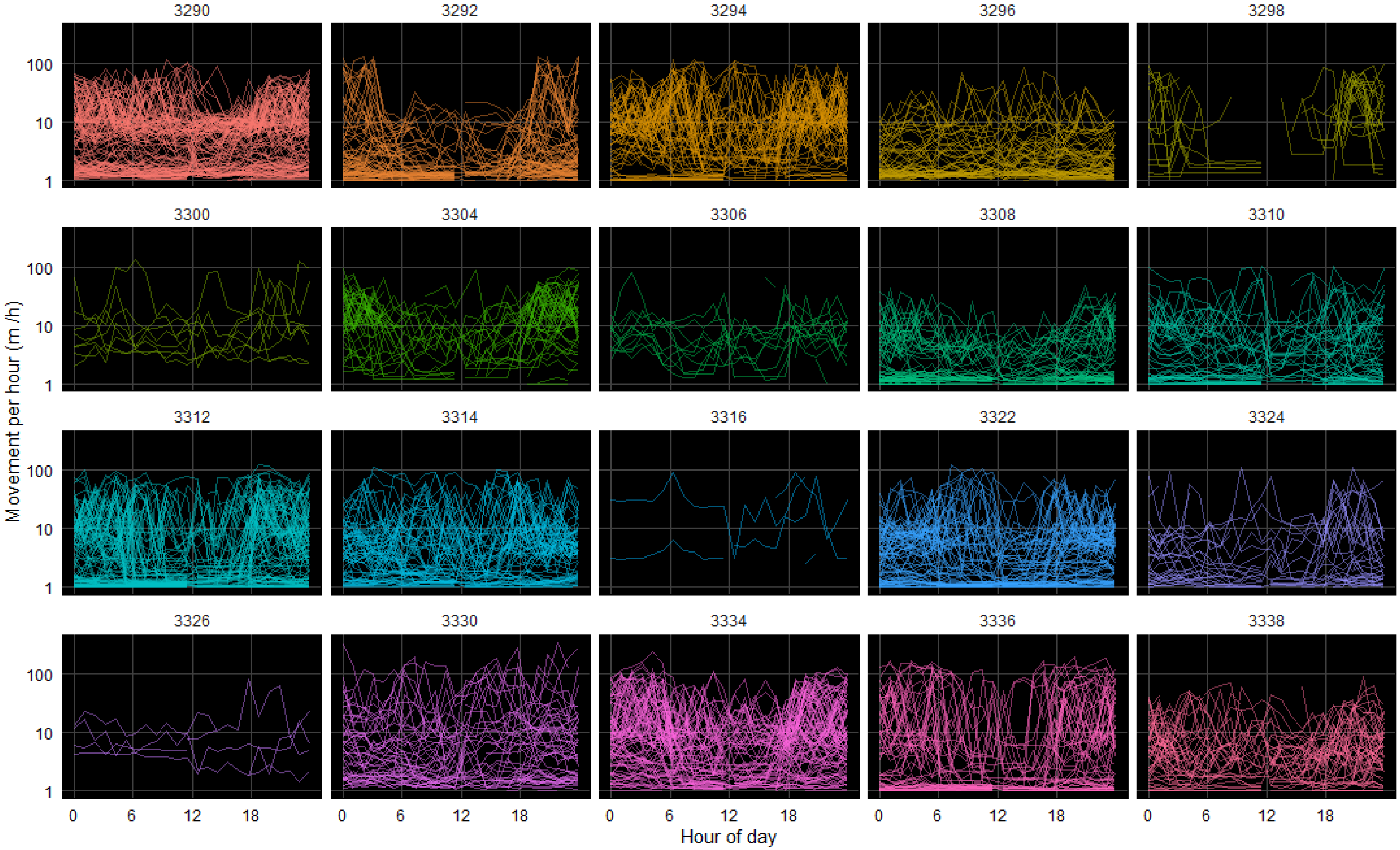

Figure 7.12. Polar plots of diurnal activity of individual lobsters as travelled distance at time of day. Colorations represent observed movements. The longer travelled distance at a given time of day, the farther away from the centre of the plot.

Periods with stationary movement, lack of detection and position fixes were used to assess when tags were lost or became inactive, and when periods with reduced detection occurred (Figure 7.11). Short periods (sub-daily to a few days) without detection and/or significant movement do not necessarily reflect loss of or tags becoming inactive and may be explained by both short-term lobster behaviour (hiding in shelter, moulting, mating, spawning and hatching eggs) and/or reduced detection range during high wind conditions when wind increase above 8-10 m/s (Figure 7.6). Lobsters are not expected to be inactive for prolonged periods of time (i.e. more than few days). Therefore, periods of more than a few days without detection and/or movement likely reflect loss of or tags becoming inactive or from lobsters moving away and out of detection range of the receiver array.

Four tags showed no significant movement albeit being detected, and are assumed lost from marking (tags 3318, 3320, 3328, 3332; data not shown), while four other tags initially showed movement but then no further detections/position fixes after two to four weeks after marking when they are assumed lost (tags 3300, 3306, 3316, 3326). Several more tags were likely lost or became inactive at different times until the end of the study, only seven lobsters had position fixes (3290, 3292, 3294, 3296, 3312, 3334, 3338) and only two lobsters (3290, 3296) showed significant movement within the last two weeks of the study (Figure 7.11).

Cumulative travelled distances varied widely from almost zero to over 25,000 m (Figure 7.11), and several lobsters showed no further movement after some time (tags 3292, 3294, 3308, 3310, 3312, 3314, 3322, 3334, 3336, 3338) or while other lobsters showed long periods with no movement followed by periods where significant movement was detected again (3290, 3292, 3296, 3310, 3312, 3324, 3334, 3336, 3338). Consequently, cumulative travelled distance can significantly underestimate actual total travelled distance during the study period.

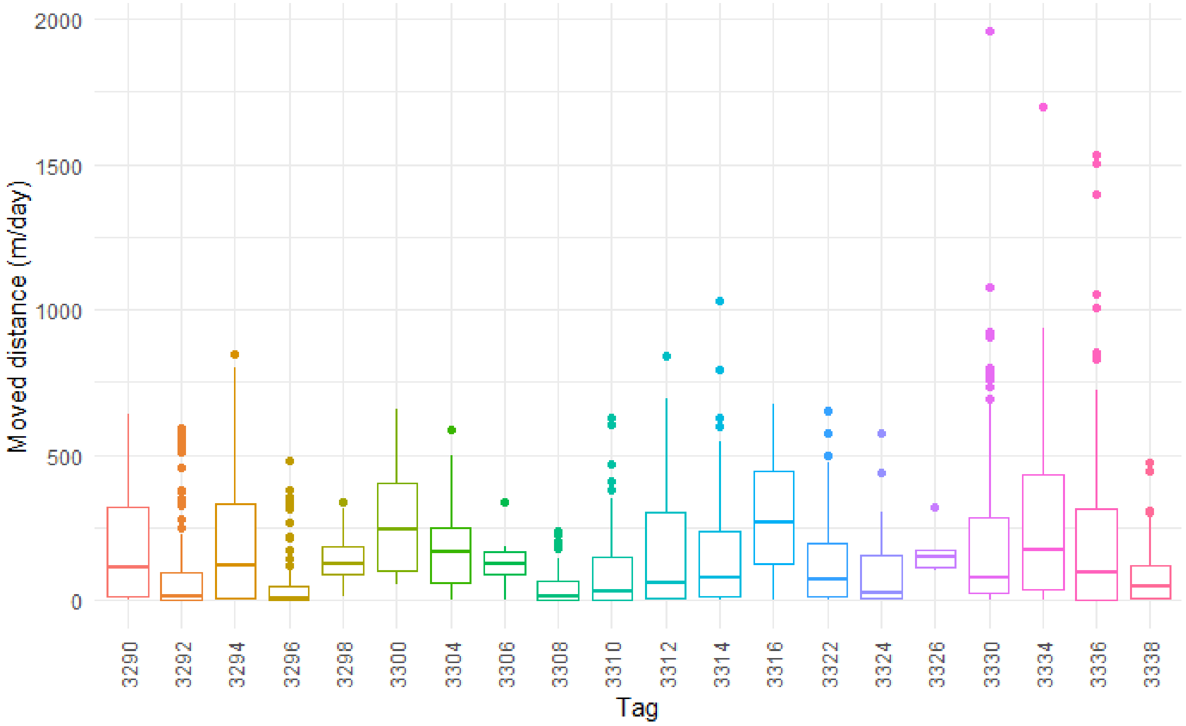

Figure 7.13. Boxplots of daily travelled distance of individual lobsters during the study period from late August 2021 to early January 2022. A few lobsters were very active with daily travelled distances beyond 1000 m, though the majority of daily travelled distances were below 500 m.

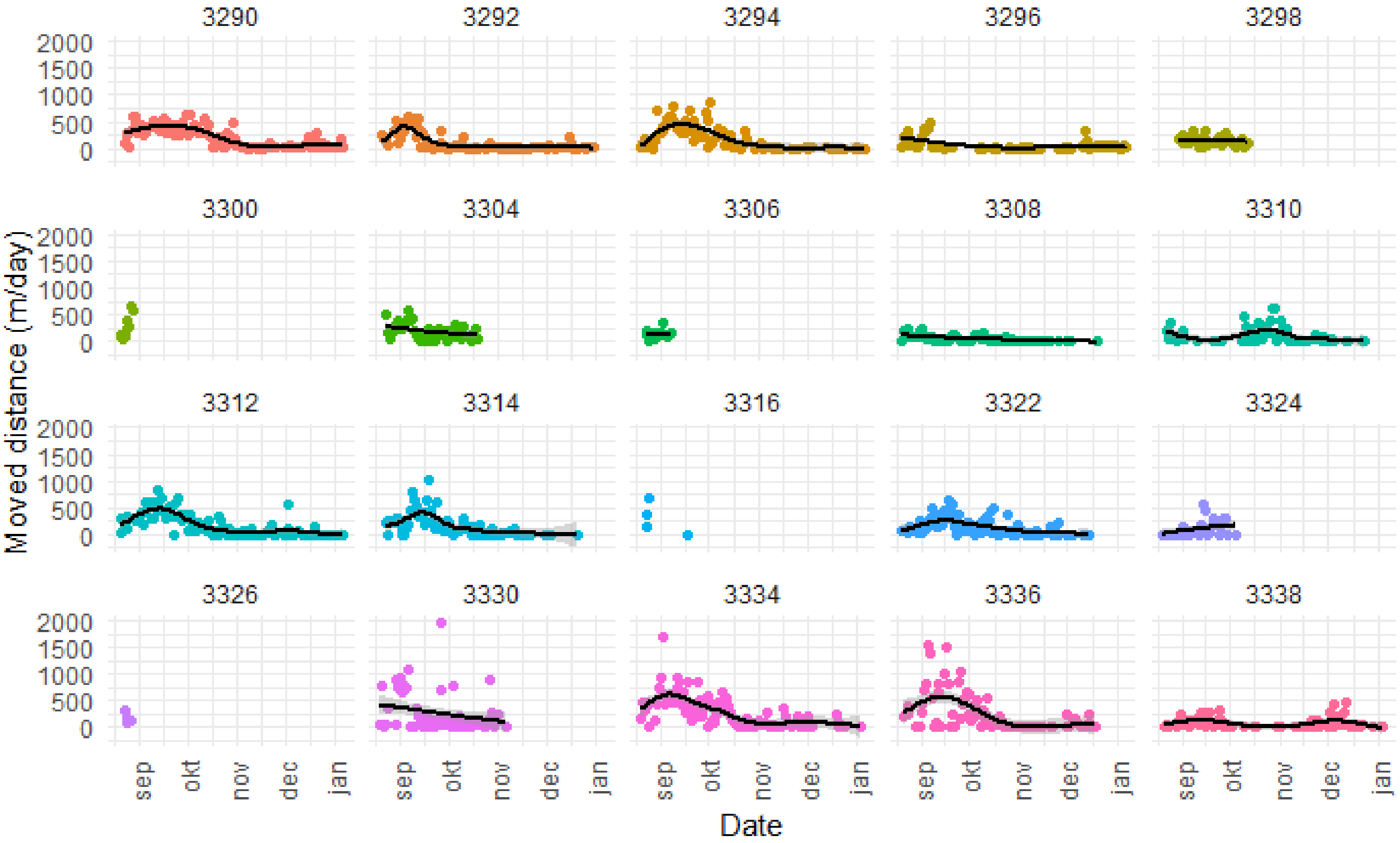

Figure 7.14. Distance travelled per day (m/day) of tagged lobsters with position fixes throughout the duration of the study.

Diurnal movement patterns

Generally, a diurnal pattern was observed with increased moved distance per hour during night-time, i.e. between 18–06 hours (Figure 7.12). While most lobsters displayed the expected higher nocturnal activity (i.e. 3290, 3292, 3294, 3298, 3304, 3308, 3310, 3312, 3322, 3334, 3336, 3338), even those lobsters also displayed significant movement during day time and a few lobsters displayed either no clear diurnal pattern or even higher activity during the day (e.g. 3296, 3314, and 3330; Figure 7.12).

Daily and seasonal movement

Daily movement of individual lobsters (m/day) ranged from close to zero to almost 2,000 m, but movements longer than 500 m occurred in a limited number of days (Figure 7.13). Median daily travelled distances by all but one lobster, were shorter than 250 m and in 15 lobsters shorter than 125 m (Figure 7.13), excluding lobsters assumed to be lost soon after tagging (3318, 3320, 3328, 3332).

Daily travelled distance by most individual lobsters generally decreased with season, being longer in summer and decreasing to minima from November to January (Figure 7.14), although a few lobsters showed a different movement pattern with longer daily travelled distances in October (3310), or even December (3338). Travelled distanced in each month was different (non-parametric Kruskal-Wallis, *H* = 369.68, df = 5, *p* < 0.0001), being highest in September and lowest in November, December, and January.

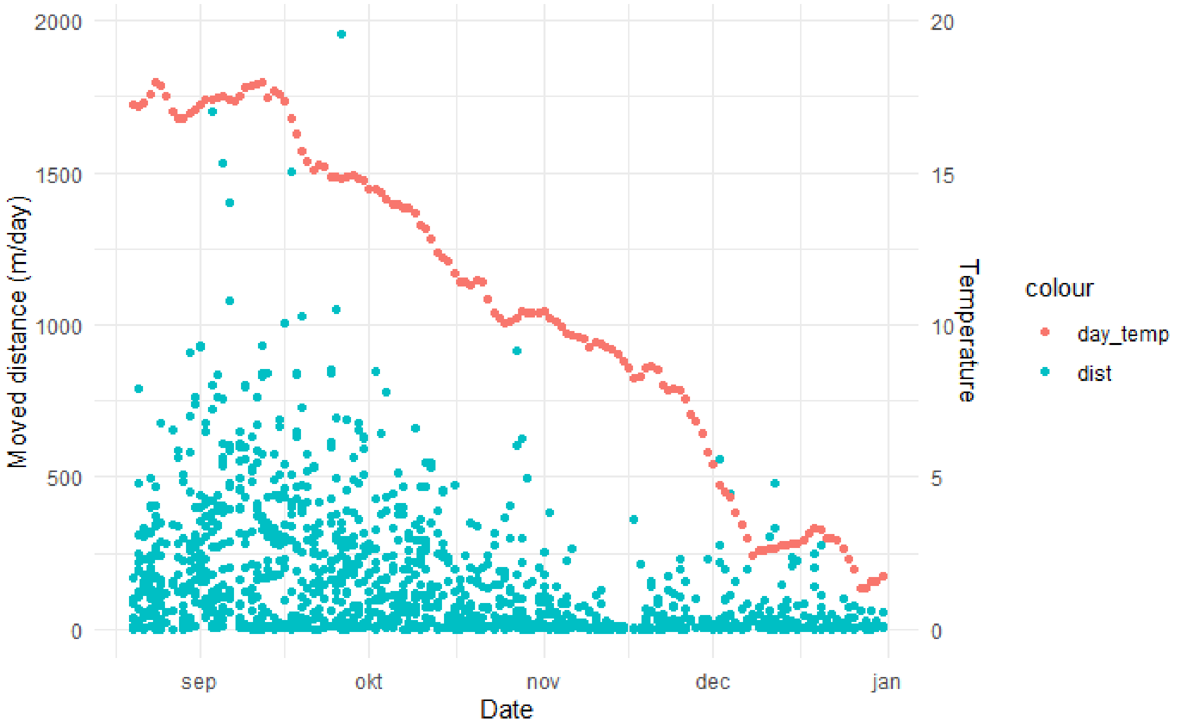

Figure 7.15. Daily travelled distance (m/day) and water temperature over the duration of the experiment from late August 2021 to early January 2022.

The decrease in daily travelled distance by lobsters paralleled the decrease in water temperature and once water temperature decreased to ca. 10-12 °C only a few daily movements were longer than 250 m (Figure 7.15). The majority of observations of travelled daily distances above 500 m occurred when water temperatures were above 10 °C, and activity decreased when the water temperature dropped below this level. A decreasing activity trend can, however, already be seen when temperatures start dropping below 12.5 °C (Figure 7.15).

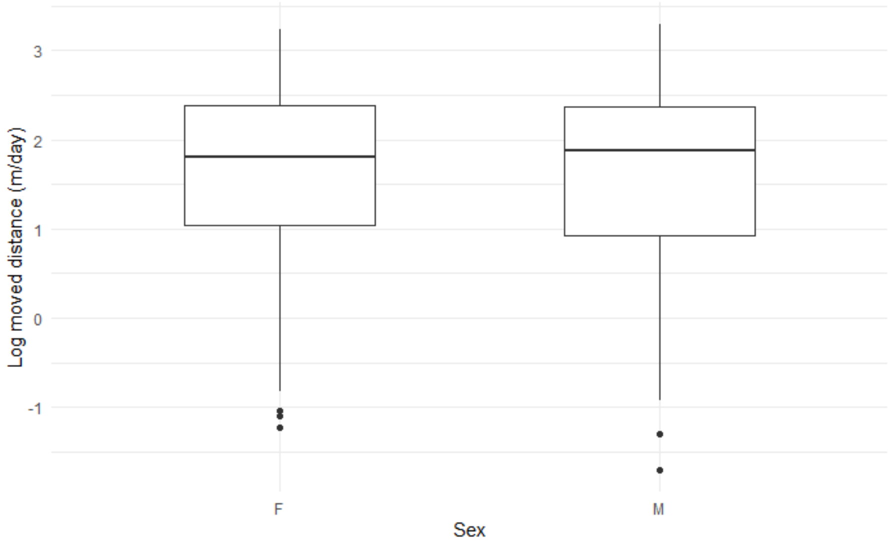

Figure 7.16. Daily travelled distance by lobsters (m/day) according to sex. M: Male and F: Female. Movement patters are similar for the sexes.

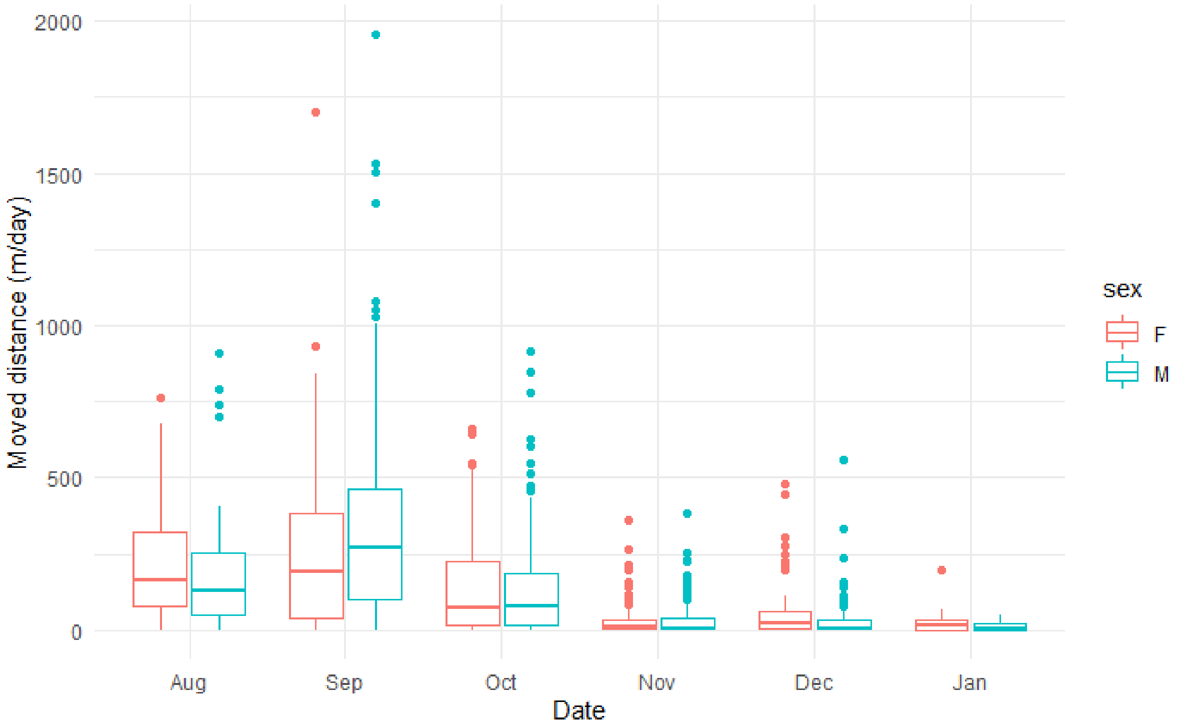

Figure 7.17. Daily travelled distance in each month by lobsters (m/day) according to sex. M: Male and F: Female. Movement patters are generally similar for the sexes.

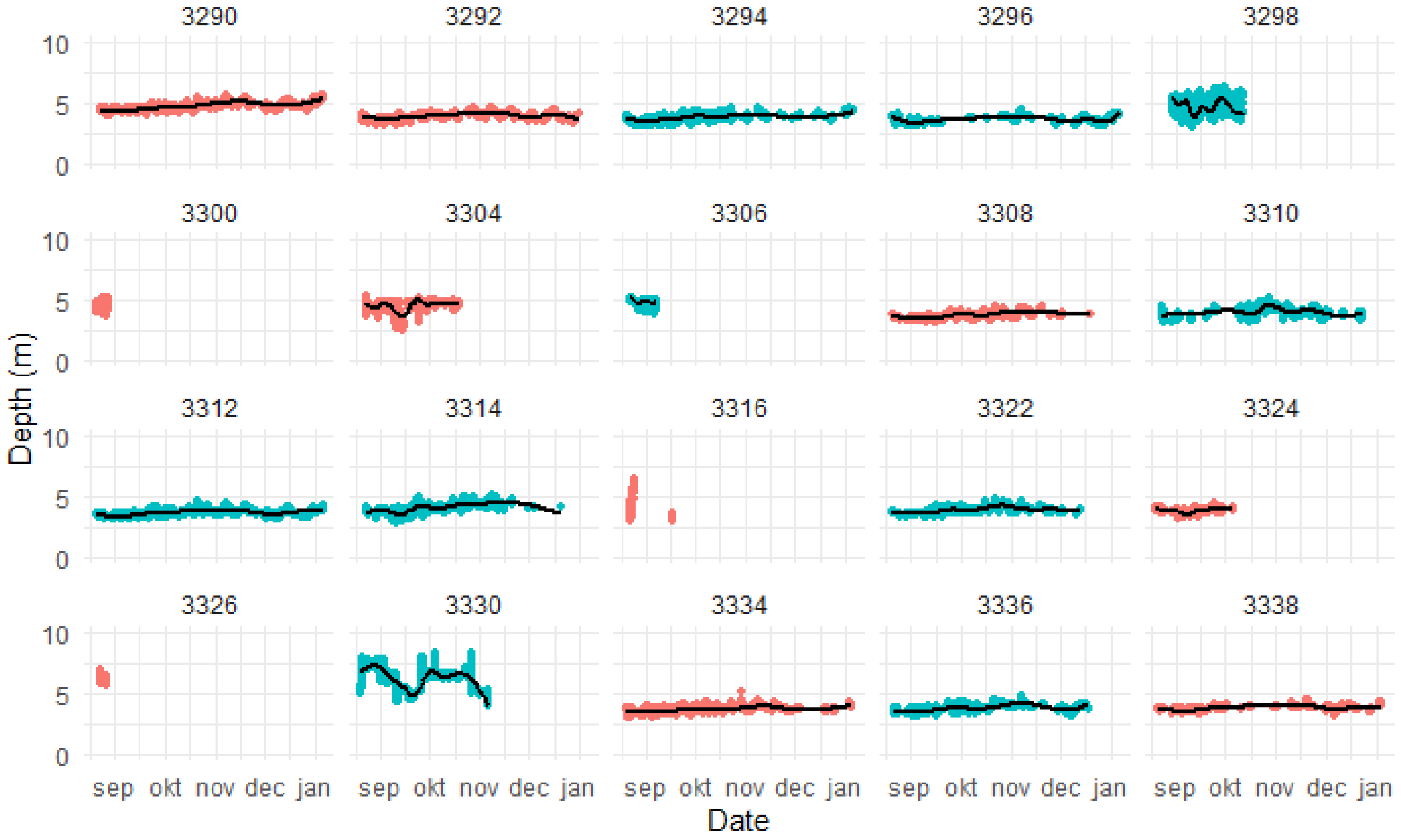

Figure 7.18. Depth (m) use of individual lobsters over the duration of the experiment from late August 2021 to early January 2022. Female lobsters in red and male lobsters in blue.

Movement differences between sexes

No significant difference was observed in mean daily travelled distance between sex for the entire study period (t-test, t = -0.945, *p* = 0.345). Mean daily distance for females and males were 148.8 ±7.76 m/day (SE, *n* = 12) and 159.8. ±8.36 m/day (SE, n = 13), respectively (Figure 7.16).

Travelled distance in each month showed a similar evolution for female and male lobsters with higher distances in August and September, decreasing in October with minimum and similar values in November, December, and January (Figure 7.17), but the small sample size of female and male lobsters, decreasing towards the end of the study, precluded statistical testing of differences.

Depth use

Individual lobsters did not show major changes in depth use over the duration of the experiment (Figure 7.18). Most lobsters remained within a depth range of one to two meters for the duration of the study, with only a few lobsters showing occasional larger and rapid changes in depth of up to 4 m, e.g. 3298, 3304, 3316, 3330 (Figure 7.18). Lobster depth use was not apparently different between sexes, with also a lack of clear seasonal change in depth use of individual lobsters (Figure 7.18).

Table 7.3. Summary of home-range statistics: number of position fixes; number of days tracked; core home range (UD50), and total home range (UD95), respectively 50% and 95% kernel density utilization distribution estimates (m^2). CL: Carapace length (mm); F: Female and M: Male.

ID	CL	Sex	N	Period	UD50	UD95
3290	97	F	2,619	August – January	925	3,625
3292	97	F	1,408	August – January	75	950
3300	72	F	190	August	1,650	11,225
3304	92	F	660	August – October	425	2,000
3308	88	F	1,175	August – December	25	450
3316	107	F	54	August – September	40,825	163,175
3324	88	F	575	August – October	1,250	6,325
3326	89	F	95	August	1,250	8,275
3334	90	F	1,904	August – January	3,500	33,950
3338	91	F	983	August – January	400	2,050
3294	90	M	1,428	August – January	950	3,625
3296	102	M	1,242	August – January	75	1,125
3298	90	M	249	August – October	375	2,900
3306	96	M	259	August – September	75	600
3310	97	M	1,065	August – December	2,100	14,200
3312	97	M	2,072	August – January	2,100	9,875
3314	101	M	1,566	August – December	1,375	6,900
3322	107	M	1,730	August – December	1,525	7,450
3330	90	M	1,048	August – November	21,700	98,775
3336	110	M	1,228	August – December	1,950	10,650

Home range

Only a single lobster moved and remained significantly outside the receiver array (ID: 3330), all other lobsters either remained inside or only occasionally moved outside the receiver array (Figure 7.19). Note that positions outside the receiver array have a higher uncertainty and its home range estimates will most probably be overestimated. All lobsters showed strong site fidelity and generally remained within 200 m from the first position fix, with only two lobsters moving more than 400 m away, 3316 and 3330 (Figure 7.19).

Total home range of individual lobsters for the entire study period estimated as the 95% kernel density utilization distribution (UD95) ranged from 450 to 163,175 m^2 (Table 7.3) with a mean value of 19,406 ±9,003 m^2 (SE, *n* = 20). However, three lobsters (ID: 3316, 3330 and 3334) had significantly larger UD95 (Table 7.3), with mean UD95 of 98,633 ±37,304 m^2 (SE, *n* = 3) while the remainder lobsters had mean UD95 of 5,425 ±1,042 m^2 (SE, *n* = 17).

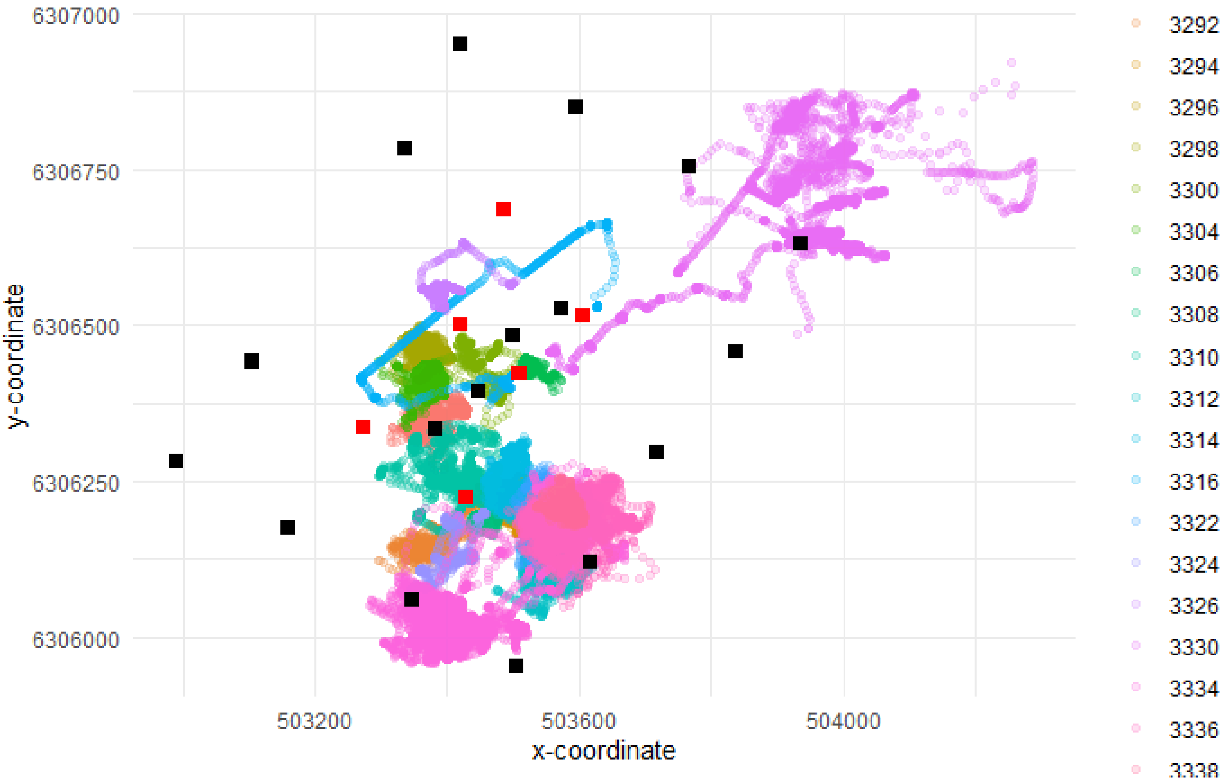

Figure 7.19. Travelled tracks of individual tagged lobsters during the study. Black squares denote the position of receivers and red squares indicate position of receivers with synctags. The figure displays a tendency for most individuals to stay within a relatively confined home range area while a few individuals perform longer excursions.

Total UD95 and core UD50 home ranges over the study period were not significantly different according to sex (Figure 7.20), either including or excluding the three lobsters with largest home ranges (ANOVA F(1,19 or 1,16) = 0.170 or 0.919, *p* = 0.685 or 0.353 and F(1,19 or 1,16) = 0.162 or 1.374, *p* = 0.692 or 0.259, respectively for UD95 and UD50).

Core home range of individual lobsters for the entire study period estimated as 50% kernel density utilization distribution (UD50) ranged from 25 to 40,825 m^2 (Table 7.3) with a mean of 3,592 ±1,926 m^2 (SE, *N* = 23). As with UD95, three lobsters (ID: 3316, 3330 and 3334) had significantly larger UD50 (Table 7.3, Figure 7.20), with a mean of 22,008 ±10,776 m^2 (SE, *N* = 3) while the remainder lobsters had a mean UD50 of 830 ±171 m^2 (SE, N = 20).

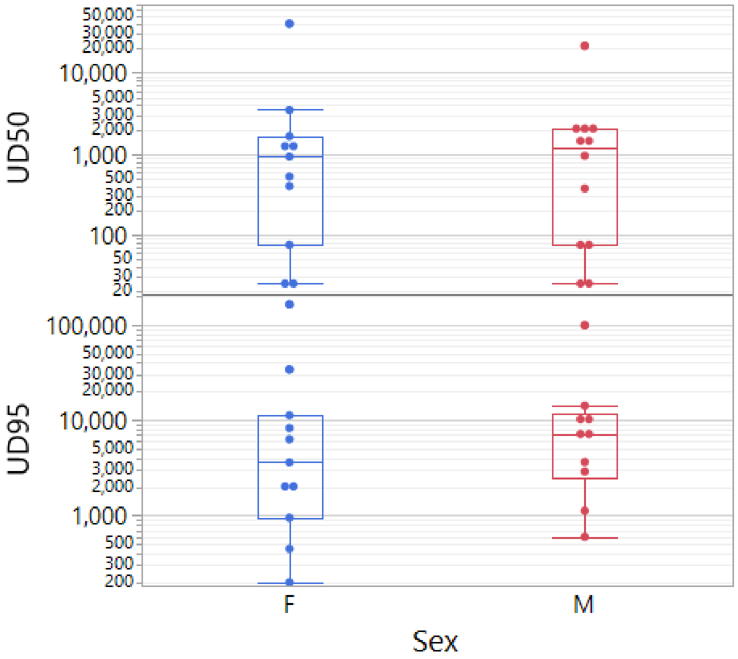

Figure 7.20. Boxplot of home range depth (m^2) from 95% utilization distribution (UD95) kernel density estimates for female and male lobsters. F: Female and M: Male. Note logarithmic Y-axis.

7.4 Discussion

Movement and activity patterns of European lobsters show considerable variation among individuals, which result from a complex influence of daily and seasonal cycles together with multiple factors, such as habitat, density, size, sex and competition for food, shelter and mating (e.g. Smith et al., 1998, 1999, 2001; Hoskins et al., 2009; Moland et al., 2011a, b; Skerrit et al., 2015; Thorbjørsen et al., 2018).

Most acoustic telemetry studies on lobster movement and activity have been done in areas deeper and with a larger range of depths than the Limfjorden (e.g. Moland et al., 2011a, Skerrit et al., 2015; Lees et al 2020), and the shallow depths of the Livø study site presented a technical challenge that impacted the detection probability of transmissions from acoustic tags carried by bottom dwelling animals such as lobsters.

A diel cycle of movement was observed in European lobsters in the Limfjorden, although possibly not as marked as in some previous descriptions of diel cycles with larger nocturnal movement and activity in both homarid species, the American lobster (e.g. Jury et al., 2005; Golet et al., 2006) and the European lobster (e.g. Smith et al., 1998; 1999; Moland et al., 2011b; Skerrit et al., 2015). Nevertheless, significant individual variability (Jury et al., 2005; Golet et al., 2006) and a seasonal decrease in the diel cycle of activity disappearing in winter (Smith et al., 1998, 1999) are to be expected.

Daily cumulative moved distance by European lobsters have only rarely been reported in the literature (Skerrit et al., 2015). In the Limfjorden from late summer to early winter, daily moved distance was usually shorter than <250 m with a mean of 149 (±5.8 SE), only on a few occasions longer than 1,000 m, and thus shorter than the 365 ±16 m (SE) reported by Skerrit et al., (2015) for the east coast of the UK during autumn. Shorter movement at the Livø telemetry study site may derive from its high habitat patchiness and complexity providing shelter density and diversity, which reduced movement in its close relative the American lobster (Hovel and Wahle, 2010). The Livø study site is also a MPA, in which a high level of residency of lobsters is expected (Huserbråten et al., 2013) potentially reducing the scale of lobster movement at the study site relative to the non-MPA location of the Skerrit et al. (2015) study.

Seasonal cycles of activity and movement have been described for the European lobster, higher when water temperature increases from spring to early autumn and decreasing during the colder winter months (e.g. Smith et al., 1998; 1999; Moland et al., 2011b). Similarly, at Livø in the Limfjorden the daily cumulative movement of lobsters tracked by acoustic telemetry generally decreased from summer to autumn–early winter, particularly from mid-October once water temperature decreased below 12–11 °C. Such seasonal drop in movement and activity fits well with landing patterns from the Limfjorden lobster fishery, which drop markedly from October onwards (Chapters 2 and 3, this report).

Depth use by individual lobsters at the Livø site in the Limfjorden generally varied by less than one to two meters depth over the study duration, even though European lobsters can show daily changes in depth of more than 20 m in Norwegian fjords (Moland et al., 2011b). The small range in depth of the Limfjorden (3 to 9 m at the Livø site), together with short scale of daily movement and home range size observed may explain the small range of depth use observed. Short fluctuations in depth use were observed in most individual lobsters (Figure 7.18), which however may not be due to lobster behaviour. Depth records from bottom dwelling tagged lobsters in this aera of the Limfjorden contain both small tidal fluctuations of ca. 10 cm amplitude and non-regular weather-related water level oscillations that can reach ± 50 cm within a day to few days (e.g. Rønbjerg Hus station from DMI and Nykøbing Mors harbour station from Morsø Kommune).

European lobsters are generally resident species, with high site fidelity and limited home ranges (UD95) from <1,000 m^2 to 40,000 m^2 (Moland et al., 2011a; Skerrit et al., 2015). Home range at the Livø site in the Limfjorden, was generally within those home ranges reported for the UK and Norway (Moland et al., 2011a; Skerrit et al., 2015) ranging between 450 and 34,000 m^2, except for two lobsters with 99,000 and 163,000 m^2 although these are likely overestimates. A facultative territorial or migratory behaviour of European lobsters has been suggested but remains unconfirmed, with a less mobile sedentary fraction contrasting with a more mobile fraction that would move over much larger distances due to intraspecific competition and size-related habitat requirements (Hoskins et al., 2011). Similarly, to its close relative the American lobster (Hovel and Wahle, 2010), home range of European lobsters can be expected to be affected habitat patchiness and complexity and conspecific density, affecting competition for shelters and food, and intraspecific predation. The diverse and complex habitat at the Livø site, provided by the stone reefs and abundant cobble mixed with soft sediment, may compensate the expected lower shelter fidelity at the high conspecific densities (Hovel and Wahle, 2010) that should result in longer movements and larger home ranges.

Movement behavioural differences between sexes and size have been observed in only a few studies (Smith et al., 2001; Skerrit et al., 2015), with male lobsters described as using more space than females (Skerrit et al., 2015), but other studies found no difference in home range size with lobster size or sex (Moland et al., 2011a; Wiig et al., 20013). However, the small sample size of this study prevents a correct evaluation of the effect of sex and size on movement and home range.

European lobsters in the Limfjorden showed strong site fidelity, as described for other locations in Norway, Sweden and the UK (e.g. Smith et al., 1998; Smith et al., 2001; Moland et al., 2011; Øresland and Ulmestand, 2013; Skerrit et al., 2015; Thorbjørsen et al., 2018). Even after one year, most recaptured lobsters in the mark–recapture study were recaptured in the same fishing ground where they were tagged at a median distance of 241 m. Nevertheless, 15% of recaptured lobsters were recaptured at over 1,000 m distance after weeks to a couple of months. In addition, only two out of 25 lobsters monitored at the Livø acoustic telemetry site moved further than a radius of 200 m from August to the following January. Even though European lobsters can move and migrate from a few km to over 45 km within one to a few years (e.g. Jensen et al., 2000; Smith et al., 2001; Huserbråten et al., 2013), only two tagged lobsters (2%) were recaptured in a different basin of the Limfjorden, at a straight line distance of 4.4 and 12 km after one and two years, respectively.

The shallow depth, relatively short distances between opposite shores and the soft bottom substrate of the deeper areas in the Limfjorden should not constitute barriers for lobster movement. Lobsters are known to move over longer distances, at larger depths and over soft substrate (Jensen et al., 1994; Smith et al., 2001; Moland et al., 2011b; Skerrit et al., 2015; Lees et al., 2020). The scale of lobster movement observed in the Limfjorden although indicating strong site fidelity for the majority of lobsters, also suggests that a fraction of the lobster population can undergo movements close to or over 1,000 m, thus allowing offshore movement between facing shores or alongshore between more suitable habitats or in response to density-drive processes (e.g. shelter or food competition) with important implications fishing impacts and replenishment of local fished grounds.

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8. Redskabseffektivitet, -selektivitet og effekt

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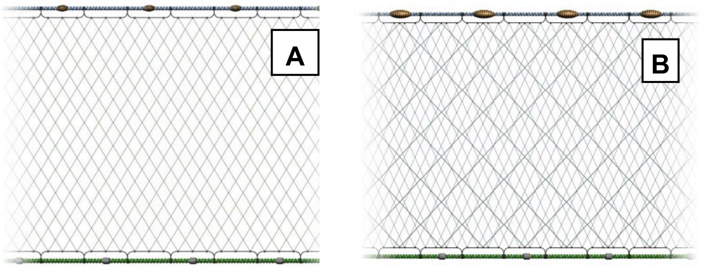
8.1 Hummerfiskeri i Limfjorden

Der er både et kommercielt og et rekreativt fiskeri efter hummer i Limfjorden (kapitel 2). Begge segmenter bruger de samme fiskeredskaber, men der er forskel på antallet af redskaber den enkelte fisker anvender. Redskaberne er:

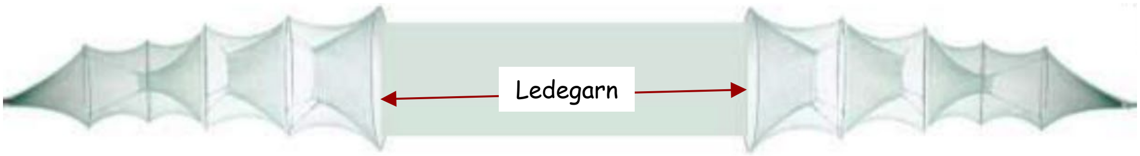
Garn og toggergarn

Garn (Figur 8.1A) og toggergarn (Figur 8.1B) er begge lavet af tynde nylontråde. De er svære at se under vand og dyr der bevæger sig over bunden vil blive viklet ind i trådene. Garn består af én netvæg mens toggergarnet har to stormaskede netvægge der omgiver en tredje væg med mindre masker. Ved fiskeri efter hummer er der ingen forskel i fangstmetoden hos de to redskaber; i begge tilfælde bliver hummeren viklet ind i de tynde nylontråde der specielt sætter sig ved deres munddele, ved overgangen mellem hovedskjold og hale, mellem halesegmenterne og i deres kløer. Garnene røgtes ved at frigøre hummeren fra nettet og i de fleste tilfælde må der skæres hul i garnet. I fritidsfiskeriet er et garn typisk 45 meter langt.



Figur 8.1. A: garn, B: toggergarn. www.seafish.org

Åleruser



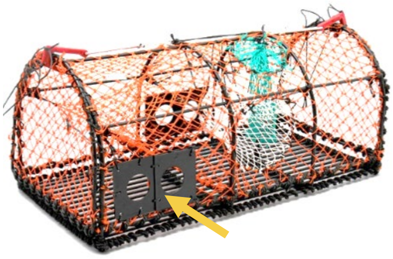
Figur 8.2. Åleruse med ledegarn og 2 ruser (dobbelt ruse). www.imr.brage.unit.no/ (FoH_5 2017)

Åleruser (Figur 8.2) bruges primært i det kommercielle fiskeri da fritidsfiskerne, af hensyn til ålebestanden ikke må bruge ruser i størstedelen af hummersæsonen. Ålerusen består af et ledegarn i midten af redskabet og de hummere, der møder ledegarnet, forventes at gå langs garnet i den ene eller den anden retning. I begge ender er der en ruse der består af en serie ringe med tragtformede åbninger ind til næste kammer. Tragten gør det svært for hummeren at finde ud af redskabet. Ålerusen er lavet af små masker som selv ikke de mindst hummere kan slippe igennem. Men i det yderste kammer er der typisk ni større firkantmasker (4x4cm), der egentlig har til formål at lukke ål ud af redskabet men som forventeligt også bruges som udslipshul af strandkrabber og en fraktion af de mindre hummer (Figur 8.3). I det yderste kammer kan fangsten bevæge sig frit og ved røgtning rystes de ud af redskabet. En åleruse er ca. 15 meter lang og den fangsteffektive del (ledegarnet) er 7-8 meter.

Figur 8.3. Udslipshuller i åleruse fra Limfjorden

Tejner

Hummertejnen (Figur 8.4) er et netbur hvor man ved hjælp af agn lokker fangsten ind gennem tragtformede indgange. Udformningen af disse gør det svært for både fisk og krebsdyr at finde ud igen. Fangsten kan bevæge sig frit i redskabet og fra Norge og Sverige er der god erfaring med at indsætte udslipshuller som de små individer kan passere igennem. Ved røgtning åbnes den ene ende af tejnen og fangsten tages ud med hånden. En hummertejne er ca. 1 meter lang.



Figur 8.4. Hummertejne med tragtformet indgang (hvidt net), agnpose (grønt net) og udslipshuller (gul pil) (www.carapax.se)

Multitejner

Multitejner (Figur 8.5), også kaldet kinatejner eller kinaruser, er et nyt redskab i dansk farvand. De består af en sammenhængende række af netbure, men til forskel fra tejnerne behøver de ikke agnes. På grund af deres længde vil de fungere som et ledegarn og således blokere vejen for hummere, der er på udkig efter føde. For hver meter er der en tragtformet indgang til et kammer. Via endnu en tragt er der adgang fra dette kammer til det tilstødende og mens fiskeriet pågår, vil de fleste hummere bevæge sig mod det yderste kammer i hver ende af redskabet. Bortset fra at bøjlerne er firkantede, fungerer de yderste kamre som ålerusen og multitejnerne røgtes på samme måde. I modsætning til de traditionelle tejner, kan multi-tejnerne klappes sammen ligesom åleruser, hvilket gør dem lette at håndtere på mindre fartøjer. De multi-tejner, der i dag er i handlen, er typisk 10-20 meter lange.

Figur 8.5. Multitejne. Hvert kammer har indgang enten fra højre side eller fra venstre side. **(www.hummetejner.dk)**

8.2 Redskabsforsøg

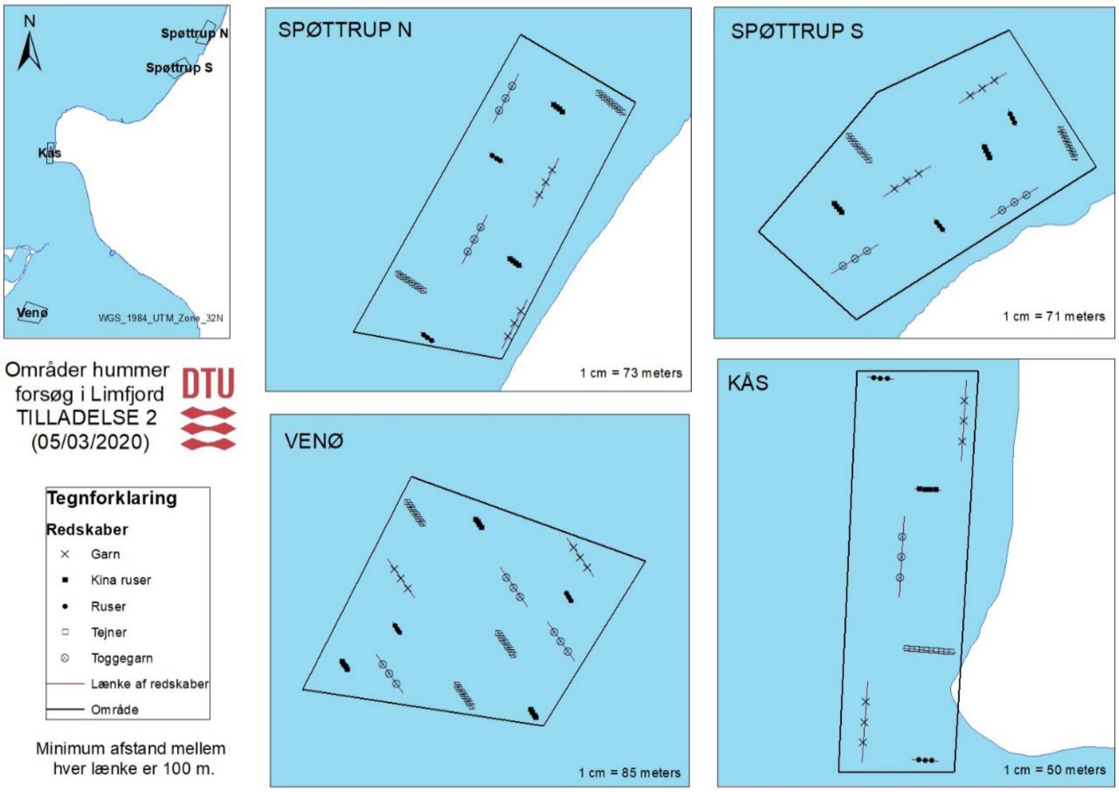
Formålet med dette forsøg var at undersøge effektiviteten af de ovenfor nævnte redskaber for at kunne fastslå hvor mange hhv. tejner, garn og multitejner, der skal til for at matche fangsten af målshummer i tre åleruser. Åleruserne er valgt som baseline, da dette redskab kan anvendes af både større og mindre både og det er velkendt af alle fiskere i området. Rigning med tre åleruser pr. lænke passede til de fartøjer, der deltog i forsøgsfiskeriet.

Metoder

Hummerfiskeriet starter i april-maj, når vandet bliver varmt nok til at hummerne begynder at bevæge sig. I 2021 var temperaturen i vandet længe om at stige, så forsøget gik først i gang i slutningen af maj.

Områderne

Vi fiskede i fire forskellige områder i hhv Kås Bredning og Venø Bugt. Områderne var udpeget som gode hummerpladser af Centralforeningen for Limfjorden og det var samtidig områder, hvor fiskerne, som deltog i forsøget, havde erfaring med at fiske hummer (Figur 8.6).



Figur 8.6. A: multitejne, B: åleruse, C: hummertejne.

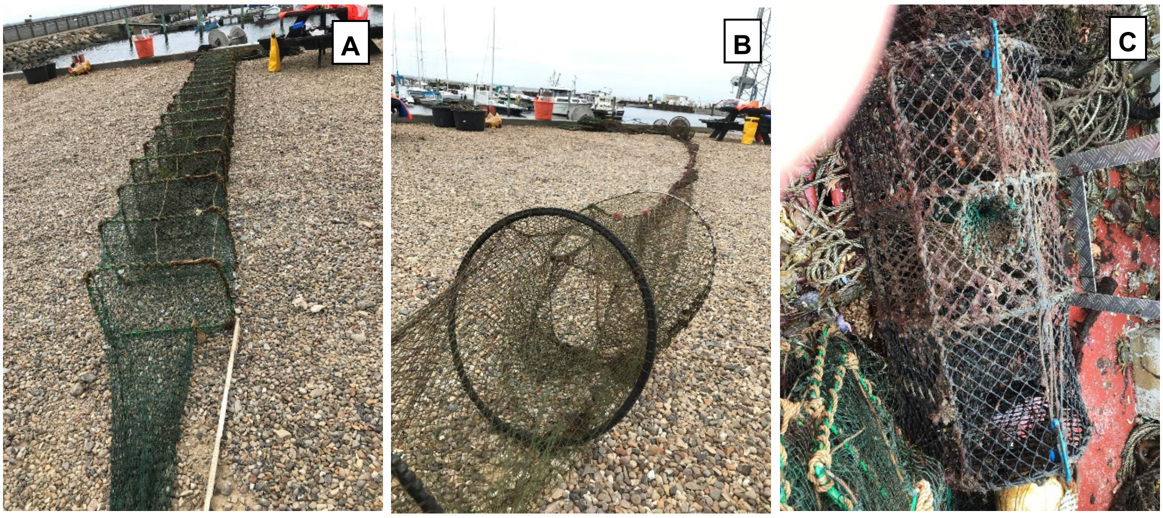
Da analyserne kræver et stort antal individer, var kriteriet for valg af områder, at det skulle være steder med forventede høje fangster af hummer. Derudover skulle der være god plads på områderne så redskaberne kunne stå med lidt afstand til hinanden. Hvis de står for tæt, er der risiko for at det ene redskab kan påvirke fangsten i et andet redskab. To fiskere med hjemhavn i hhv Sillerslev og Jegindø deltog i forsøget og blev tildelt to områder hver.

Fiskeriet

Afhængigt af vejret blev redskaberne røgtet hver 3. til hver 6. dag og når vejret tillod det, blev alle fire områder røgtet samme dag. Området ”Kås” er dog mere vindfølsomt end de andre og det var derfor ikke altid muligt at røgte dette. For at sikre at alle redskaber fiskede på lige gode pladser blev de så vidt muligt flyttet rundt inden for området ved hver røgtning. Ved Spøttrup N og Spøttrup S var dette imidlertid svært, da andre fiskeres redskaber optog en del af pladsen.

I hvert område var der (Figur 8.7):

2 lænker á 4 multitejner – længde pr multitejne: 10 m (Fig 8.6A)
2 lænker á 3 åleruser – længde pr åleruse: 15 m (Fig 8.6B)
2 lænker á 10 tejner agnet med saltet fisk (Fig 8.6C)
2 lænker á 3 garn – maskestørrelse 110 mm halvmaske
2 lænker á 3 toggergarn – maskestørrelse 75 mm halvmaske



Figur 8.7. A: multitejne, B: åleruse, C: hummertejne.

Fangsterne

Det stod hurtigt klart at bifangst af fisk var minimal og derfor fokuserede vi alene på hummerfangsten. Hummerne blev kønnet og hovedskjoldet på hver hummer blev længdemålt med en digital skydelære. Derudover registrerede vi om hummeren var blød pga. nyligt skalskifte og for hunnerne; om der var rogn.

Bifangster af undermålshummer

Undermålshummere, der fanges og returneres, risikerer at have nedsat tilvækst og dermed være længere tid om at indgå i fiskeriet end hvis de ikke var blevet hevet til overfladen. Årsagerne til dette er blandt andet:

<u>Tab af ben, klør og følehorn</u>. I tejner, åleruser og multitejner er der en risiko for at hummerne slås og derved kan miste ben og klør. I garn og toggergarn er risikoen for at miste ben eller kløer primært forbundet med røgtningen. For andre arter af hummer er det vist at den energi der bruges til at regenerere tabte lemmer ved næste skalskifte medfører at længdetilvæksten mindskes (Brouwer et al., 2006; Brown og Caputi, 1984; Emery et al., 2016).

<u>Tab af territorie</u>. Når en hummer genudsættes, udsættes den ikke nødvendigvis der hvor den blev fanget og havde territorie. Dette øger risikoen for at den bliver spist eller kommer til skade i den efterfølgende rivalisering (Brown og Caputi, 1984).

Ud over disse potentielle effekter, vil en hummer der har mistet én eller begge kløer være mindre værdifuld ved salg end en hummer, der har begge kløer intakte.

Dataanalyse

Fangsteffektivitet og discard

Fangster af hummer i de forskellige redskaber blev analyseret i en såkaldt catch-comparison analyse. Her sammenlignes antallet af hummere i de enkelte længdegrupper i to forskellige redskaber. I disse analyser medtages kun de ture, hvor begge typer redskaber i den pågældende analyse er med. Dermed kan vi antage at alle redskaberne i analysen har fisket under ens forhold, og at fangsterne derfor ville have været sammenlignelige, hvis ellers redskaberne var lige effektive. Resultatet af en sådan catch-comparison analyse afslører om et redskab fanger signifikant flere eller færre individer af en serie længdegrupper og dermed også om det ene redskab fanger signifikant flere målshummer.
Da vi har valgt lænken med tre åleruser som baseline, sammenligner vi de øvrige redskaber op imod dette. Fangsteffektiviteten af et redskab betegnes som sandsynligheden for at en hummer over målet fanges i lænken med de tre åleruser eller i det andet redskab *(pAbove)*. Hvis denne værdi er over 100 er det andet redskab mere effektivt end de tre åleruser. Signifikante forskelle identificeres ved manglende overlap af 95% konfidensintervallet.

Efterfølgende kalibreres de forskellige redskaber ift. deres fangsteffektivitet. Dermed bliver det muligt at vurdere hvor mange af én slags redskaber, der skal til for at opnå tilsvarende fangster af hummer over målet som i en lænke med tre åleruser (formel 1).

Formel 1: $3\ \text{å}leruser = \frac{N_{redskab}}{pAbove_x}$

Hvor $N_{redskab}$ er antallet af det pågældende redskab, der fiskes i en lænke og $Pabove_x$ der er den beregnede sandsynlighed for, at en hummer vil blive fanget i redskab x fremfor i åleruserne.

Discard-ratioen af undermålshummer i et redskab, beregnes som antallet af undermålshummer / antallet af alle hummer. Discard-ratio'en er uafhængig af hvor mange redskaber, der er fisket med.

Fangster af bløde hummer og rognhummer

I snit var det omkring 1/3 af målshummerne, der havde rogn og derudover var der en del bløde. Men da begge dele varierer over sæsonen, er der i analysen af fangsteffektivitet kun taget højde for om hummeren er over mindstemålet eller ej.

Resultater

I perioden fra den 13/5 2021 til den 25/6 2021 gennemførte vi i alt syv fulde fiskedage med en total fangst af 1887 hummere hvoraf 368 individer svarende til ca. 150 kg var over mindstemålet på 87 mm. Med andre ord var i gennemsnit 80% af de fangne hummere under mindstemålet. Som det ses af Tabel 8.1 blev hvert redskab fisket 20-25 gange om end fordelingen ikke er helt balanceret i de fire områder. Men som beskrevet ovenfor, er der taget højde for dette i dataanalysen.

Tabel 8.1. Antal lænker fisket med det pågældende redskab i de forskellige områder.

	Toggergarn	Tejner	Multitejner	Åleruser	Garn
Kås	4	6	6	6	5
Venø	6	7	7	7	6
Spøttrup N	5	6	6	6	5
Spøttrup S	5	6	6	6	5

Fangsteffektivitet

Antallet af hummere, der kunne landes, varierede ikke kun fra redskab til redskab men også mellem områderne (Tabel 8.2). Da der i denne oversigt ikke tages højde for at alle redskaberne ikke er fisket lige mange gange i de forskellige områder, bruges den ikke til at estimere den relative fangsteffektivitet.

Effektiviteten af de forskellige redskaber estimeres ved at sammenligne antallet af hummere over mindstemålet i en lænke af Redskab X med den tilsvarende fangst i tre åleruser (Tabel 8.3). Ved en effektivitet på 100 er de to redskaber lige effektive til af fange målshummer. Hvis effektiviteten >100 er redskab X mere effektiv og hvis effektiviteten <100 er ålerusen mest effektiv. Fangsteffektiviteten er signifikant højere i lænkerne med fire multitejner end i lænker med tre åleruser (Tabel 8.3). Ingen af de andre redskabers effektivitet er signifikant forskellig fra effektiviteten af åleruser, men uanset bruger vi middelværdierne til at kalibrere fangsteffektiviteten i de forskellige redskaber. Således estimerer vi at fangsterne af målshummer i 2,1 (1,38 – 3,45) multitejner svarer til fangsten i tre åleruser (Tabel 8.3). Som enkeltstående redskab er tejnerne de mindst effektive. Her skal der 9,7 (6,29-16,64) tejner til at opnå samme antal målshummer som i tre åleruser (Tabel 8.3). Garn og toggergarn er omtrent lige effektive, når det kommer til fangst af målshummer og for disse redskaber skal der hhv. 2,3 (1,50-3,51) og 2,3 (1,24-6,52) redskaber til for at fange et antal målshummer, der tilsvarer fangsten i tre åleruser.

Tabel 8.2. Gennemsnitligt antal hummere fanget pr lænke i de forskellige områder og redskaber.

	Toggergarn	Tejner	Multitejner	Åleruser	Garn
Kås	1,25	0,82	1,67	0,49	1,00
Spøttrup N	0,60	1,00	1,33	0,42	0,50
Spøttrup S	0,20	0,50	1,92	1,17	1,10
Venø	1,58	1,57	2,46	0,96	0,75

I Tabel 8.3 er det også angivet, hvor langt et kalibreret redskab vil være og dermed også hvor meget fiskeplads / havbund det vil optage. Hvis den totale længde af redskaberne tages i betragtning, er multitejnen betydeligt mere pladsbesparende end de øvrige redskaber. Hvis man alene ser på den del af redskabet, der er fangsteffektiv (ledegarnet i ålerusen og selve tejnen i hummertejner), ligger multitejner og åleruser på linje, mens tejner fylder mindst på bunden.

Tabel 8.3. Parvis sammenligning af fangsteffektiviteten i tre åleruser og hhv. toggergarn, tejner, multitejner, eller garn. Effektiviteten er angivet som sandsynligheden for at en målshummer fanges i RedskabX frem for i åleruser. Kalibreret antal redskaber angiver det antal redskaber der i effektivitet svarer til tre åleruser med længden af den fangsteffektive del i parentes. Effektivitet og kalibreret antal redskaber er angivet som middelværdi med 95% konfidensinterval i parentes. *værdier i parentes er den del af redskabet, der er fangsteffektiv.

		Effektivitet	Kalibreret antal redskaber	Længde af kalibreret redskab (m)	Discard-ratio (undermåls / total)
Redskab X	Togger	131,4 (46,0-241,9)	2,3 (1,24-6,52)	120	70,2 %
	Tejne	103,1 (60,1-159,1)	9,7 (6,29-16,64)	100 (10)*	85,6 - 87,2 %
	Multitejne	189,2 (115,8- 289,4)	2,1 (1,38-3,45)	20	83,7 - 85,0 %
	Garn	130,5 (85,5-200,0)	2,3 (1,50-3,51)	120	56,5 - 58,1 %
	Åleruser	Ikke relevant	3	45 (23)*	73,4 - 75,4 %

Discard-ratioen af undermålshummer er høj i alle redskaber. Således er 56-87% af de hummere der fanges, for små til at blive landet. Den laveste andel af undermålshummer finder vi i garn og herefter følger toggergarn og åleruser, mens tejner og multitejner har den højeste andel af undermålshummer. Bifangsterne af undermålshummer afspejler maskestørrelserne, der er mindst i tjener og multi-tejner.

Som nævnt tidligere var bifangsten af fisk i dette forsøg lille og bestod af få individer over hele forsøgsperioden. Af andre arter havde især garn og toggergarn bifangst af taskekrabber mens tejner, multitejner og åleruser havde bifangster af især strandkrabbe og taskekrabber.

8.3 Estimering af optimal størrelse på udslipshuller og den teoretiske effekt på fangstsammensætningen

Udslipshuller giver undermålshummer en mulighed for at slippe ud af redskabet mens det står på bunden. Udslipshuller anvendes i dag i flere hummerfiskerier med tejner bl.a. i Norge og Sverige. Der er ingen tilgængelig dokumentation af effekten af disse udslipshuller fra Sverige, men i Norge har man observeret et markant fald i andelen af hummerfangster under mindstemålet efter indførelsen af krav om udslipshuller (Kleiven et al., 2017). I England anvender man også udslipshuller i tejnefiskeriet efter hummer og her har undersøgelser vist at udslipshullerne både reducerer antallet af undermålshummer og samtidig øger antallet af målshummer (Brown, 1982).

Formålet med dette forsøg er at estimere den optimale størrelse af udslipshuller til fiskeriet i Limfjorden, hvor mindstemålet for hummer er 87 mm rygskjold.

Metode

Vi har undersøgt, hvilke størrelser af hummer der, ud fra et morfologisk synspunkt, er i stand til at slippe gennem en serie af cirkulære og kvadratiske udslipshuller. Metoden hedder FishSelect og er international anerkendt og meget velegnet til undersøgelser som denne. Undervejs i redskabsforsøget beskrevet ovenfor, indsamlede vi løbende 224 hummer i hele størrelsesspektret (47-135 mm). Derpå testede vi, hvorvidt hver enkelt af disse hummer kunne slippe gennem en serie af huller udskåret i en nylonplade (Figur 8.8). Vi holdt hummeren i kløerne og lod alene tyngdekraften hjælpe hummeren på vej. Undersøgelsen af den enkelte hummer tog mindre end ét minut, hvorefter undermålshummerne blev genudsat. Bløde hummer og rognhummer indgik ikke i forsøget.

Selvom der er stor morfologisk forskel på hunner og hanner fandt vi ingen tegn på at kønnet påvirkede resultatet i dette forsøg. Kønsforskellene ligger primært i størrelsen af kløer og bredde af halesegmenter, men det var omkredsen af rygskjoldet, der viste sig at være afgørende for om hummeren kunne passere et udslipshul eller ej. Derfor vurderede vi også at tilstedeværelsen af rogn ikke ville påvirke resultatet. Rognhummerne blev derfor genudsat med det samme.

Figur 8.8. Forsøgsopstilling med plade med ”udslipshuller” og en hummer, der holdes i kløerne. Halefligene samles så det ikke er dem, der forhindrer gennemfald.

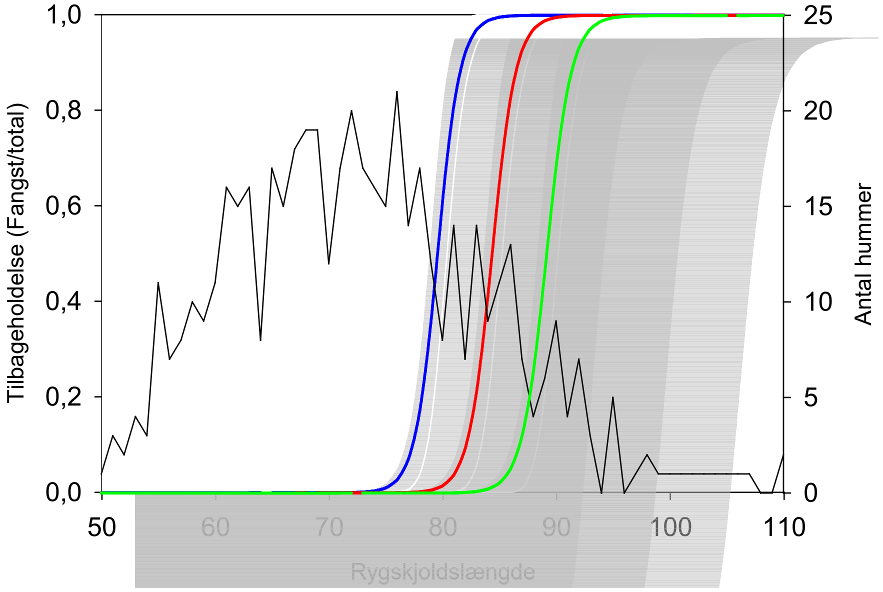
Dette forsøg giver viden om sandsynligheden for at en hummer af en given længde kan slippe igennem hver enkelt af de testede huller. De cirkulære og kvadratiske huller blev analyseret separat i et multimodel-setup, hvor størrelsen af hullet indgik som variabel. Kombinationen af modeller der bedst forklarer data, brugte vi til at forudsige, hvor stor sandsynligheden er for at hummer af forskellig størrelse er i stand til at passere specifikke udslipshuller.

Da der ikke var nogen form for udslipshuller i tejnerne, bruger vi hummer fra dette redskab som "baggrundspopulation". Ved at gange hver længdegruppe i denne population med sandsynligheden for at denne størrelse hummer slipper ud, kan vi forudsige hvilken effekt et udslipshul af denne form og størrelse potentielt kan have på hhv. tab af målshummer og reduktion i undermålshummer (discarden).

Da der allerede produceres cirkulære udslipshuller til brug i det norske og svenske fiskeri og da det var en udbredt holdning på møderne at en eventuel regulering på området skulle være så enkel som mulig, har vi i det følgende alene fokuseret på de cirkulære udslipshuller.

Resultater

Ikke overraskende er der en tydelig sammenhæng mellem størrelsen af udslipshullet og chancen/risikoen for at en hummer af en bestemt størrelse rent fysisk kan slippe ud af redskabet (Figur 8.9).



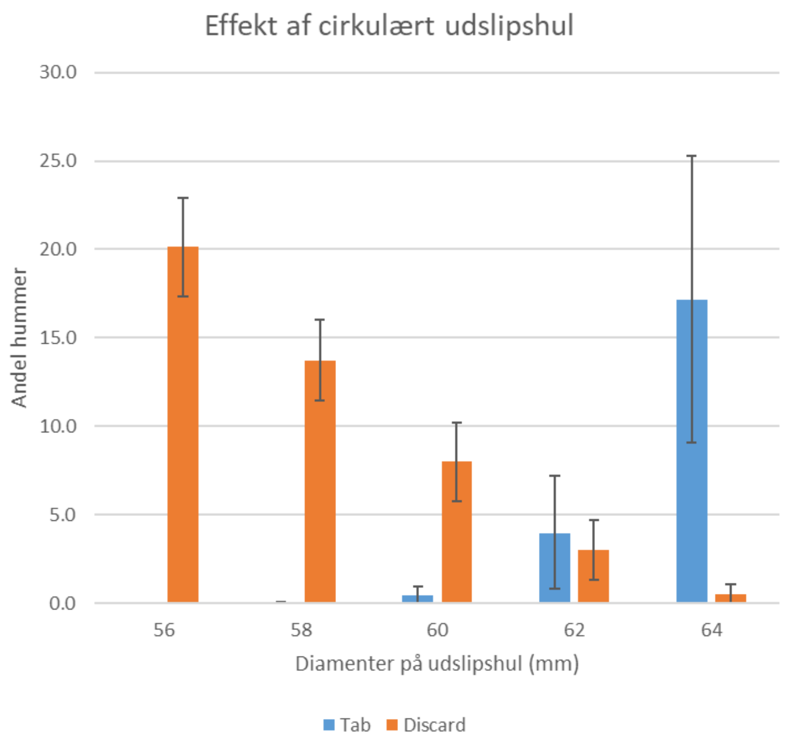
Figur 8.9. Den modellerede tilbageholdelse af hummer i cirkulære udslipshuller med en diameter på 56 mm (blå), 60 mm (rød) og 64 mm (grøn) med 95% konfidensbånd. Størrelsessammensætningen af hummer, der blev fanget i tejnerne, er vist med sort.

Med den størrelsessammensætning, der var på fiskepladserne i Limfjorden i dette forsøg, kan vi estimere, hvor stor en andel af hummerne over og under mindstemålet på 87 mm, der vil være i stand til at passere gennem et udslipshul af en given størrelse (Figur 8.10). Hvis der eksempelvis kan accepteres et tab af målshummer på op til 5% i antal, vil det med et cirkulært hul med en diameter på 60 mm, være fysisk muligt for 90-94% af undermålshummerne at slippe ud. Der vil således være en potentiel reduktion i discarden på 90-94%.

Målshummer der tabes fra fangsten fordi de undslipper via udslipshullet på 60 mm vil bestå af de længdeklasser, der ligger lige over mindstemålet. Der er således 3% risiko for tab af en hummer der måler 87 mm, 1,2 % risiko for at miste en hummer på 88 mm og under 1 procents risiko for at miste hummer der er 89 mm eller større (Tabel 8.4).

Tabel 8.4. Risiko for tab af forskellige længdegrupper ved brug af et cirkulært udslipshul på 60 mm. Risikoen er angivet i procent og 95% konfidensintervallet ses i parentes.

SKJOLDLÆNGDE	86 MM	87 MM	88 MM	89 MM	90 MM
RISIKO (%)	7,4 (0,7-14,1)	3,0 (0,0-6,0)	1,2 (0,0-2,5)	0,4 (0,0-1,0)	0,2 (0,0-0,4)



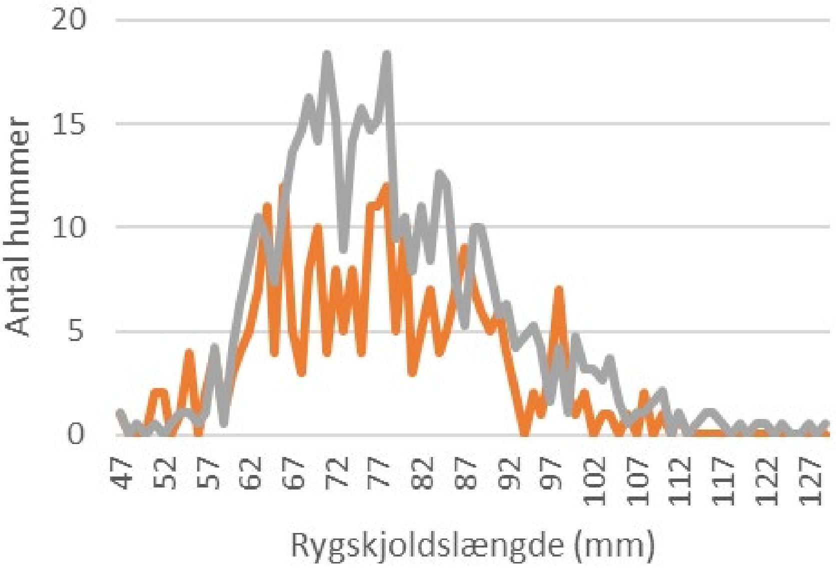
Figur 8.10. Potentiel effekt på hhv. tab af målshummer (blå) og discard af undermålshummer (orange) ved brug af cirkulære udslipshuller af forskellig størrelse.

I dette del-forsøg så vi alene på om det var fysisk muligt for hummerne at slippe ud gennem udslipshullerne eller ej. Da ikke alle hummer forventes at lokalisere og benytte udslipshullet vil vores estimering af reduktionen af discard være for høj mens vores estimat af risikoen for tab af målshummer vil være for lav. Data fra dette forsøg bruger vi derfor som et pejlemærke for et efterfølgende forsøg, der er beskrevet i næste afsnit.

8.4 Placering af udslipshuller i multitejner

Baseret på resultaterne fra ovenstående forsøg blev det besluttet i projektgruppen at teste et rundt udslipshul, da der er gode erfaringer med dette i hummertejner i vores nabolande. I I bl.a. Norge og Sverige anvendes udslipshullerne i de traditionelle hummertejner, og deres placering er allerede velbeskrevet. Derimod mangler vi viden om hvorvidt sådanne udslipshuller kan opnå samme effekt på størrelsessammensætningen i deformérbare redskaber som ruser og multitejner. For med stor sikkerhed at kunne estimere størrelses-selektionen for sådan et udslipshul, er vi afhængige af at der er mange hummer der er små nok til at slippe ud, samtidig med at mange er for store. Fra forsøget i 2021 havde vi kendskab til størrelsesfordelingen af hummer i området (Figur 8.9) og heraf er det tydeligt at der ikke er mange hummer over 90 mm. På trods af at den optimale diameter ift. mindstemålet var vurderet til at være 60 mm, valgte vi derfor at teste et udslipshul på 55 mm hvor der var større sikkerhed for at få nok individer i løbet af forsøget. Med disse data i hus, er det en standardøvelse at ekstrapolere resultaterne til andre størrelser af udslipshuller.

I åleruserne er der som nævnt allerede udslipshuller beregnet til ål. Multitejnerne har nogenlunde samme maskestørrelse som åleruserne og fangstmetoden er identisk, så hvis ikke hummerne benytter sig af udslipshullerne, forventer vi at størrelsessammensætningen i de to redskaber vil være ens. Imidlertid, viser resultaterne, at der var markant færre individer mellem 55 og 80 mm i ålerusen end i multitejnen (Figur 8.11), hvilket indikerer at udslipshuller lokaliseres og benyttes af hummerne.



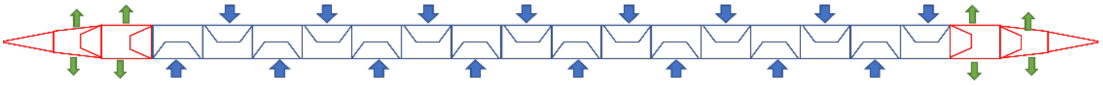
Figur 8.11. Størrelsesfordeling af hummer fanget i tre åleruser (orange) og i 2.1 multitejner (grå). Der er markant færre små hummer i åleruserne hvor der er udslipshuller.

Placeringen og antallet af udslipshuller har uden tvivl indvirkning på deres effektivitet. I Norge og Sverige, hvor de er lovpligtige i tejner, skal de således placeres nederst på siden i hvert kammer, men konstruktionen af både åleruser og multitejner er lidt mere komplicerede og det skal undersøges, hvilken løsning der fungerer bedst i disse redskaber. I juni 2022 gennemførte DTU Aqua derfor et forsøg i Limfjorden, hvor vi testede forskellige placeringer af cirkulære udslipshuller med en diameter på 55 mm i multitejner. I forhold til hummertejnen er multitejnen et langt redskab og forsøget skulle undersøge om det var mere sandsynligt at undermålshummerne slap ud, hvis der var mange (16) udslipshuller end hvis der var få (8).

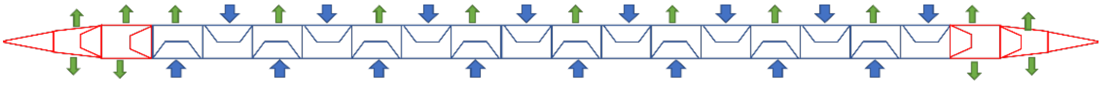
Figur 8.12. Placering af udslipshuller i opsamlingskamre i multitejne. Bemærk at udslipshullerne er placeret skiftevis højt og lavt samt væk fra kalven.

Mange multitejner er designet så det er tilfældigt om det er toppen eller bunden, der vender opad, når den lander. I samråd med fiskerne placerede vi derfor udslipshullerne skiftevis øverst og nederst på siden af multitejnen (Figur 8.12).

I multitejnerne med **få udslipshuller** var udslipshullerne kun installeret i de to opsamlingskamre (kamre, der kun har indgange fra andre dele af redskabet) i enderne af redskabet. I hvert af disse kamre var to udslipshuller placeret således at det ene flugtede med overkanten af redskabet og det andet med underkanten (Figur 8.13).


Figur 8.13. Multitejne set fra oven med indgange (blå pile) og 8 udslipshuller (grønne pile) placeret i opsamlingskamrene (røde segmenter).

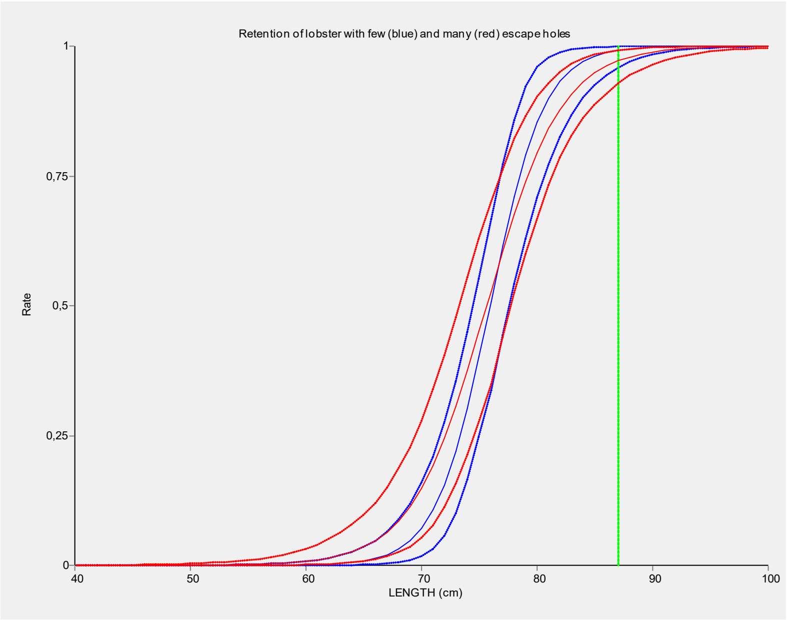
Multitejnerne med **mange udslipshuller** var identiske med dem med få, bortset fra at der var isat yderligere 8 udslipshuller skiftevis øverst og nederst på siden af multitejnen (Figur 8.14).


Figur 8.14. Multitejne set fra oven med indgange (blå pile) og 16 udslipshuller (grønne pile) placeret i hele redskabets længde.

I forbindelse med det kommercielle fiskeri blev der indsamlet hummer i hele størrelsesspektret. Hver enkelt hummer blev målt og markeret med et V-hak i halen. Til formålet var der konstrueret tejner som vist i Figur 8.13 og 8.14, men med alle indgangene undtagen det midterste lukket. 5-12 forsøgshummerne blev sat ned i det midterste kammer hvorefter denne indgang også blev lukket. Tejnerne blev genudsat og eneste vej ind og ud af tejnen ville nu være gennem udslipshullerne. Da forsøgshummerne var mærket med et V-hak i halen, kunne vi ved røgtningen efter 2-5 dage se om der var kommet nye hummer til. Kun forsøgshummerne indgik i analyserne.

Ved røgtningen blev hummerne målt igen og ved at matche størrelsessammensætningen var det muligt at se, hvilke hummer der var sluppet ud af tejnen i løbet af forsøget.

Analysen af disse data viste at der ikke var signifikant forskel på selektionen i de to multitejne-design (Figur 8.15). Det er derfor tilstrækkeligt at have to udslipshuller i hvert opsamlingskammer (I alt 8 udslipshuller i det testede design) (Figur 8.13).



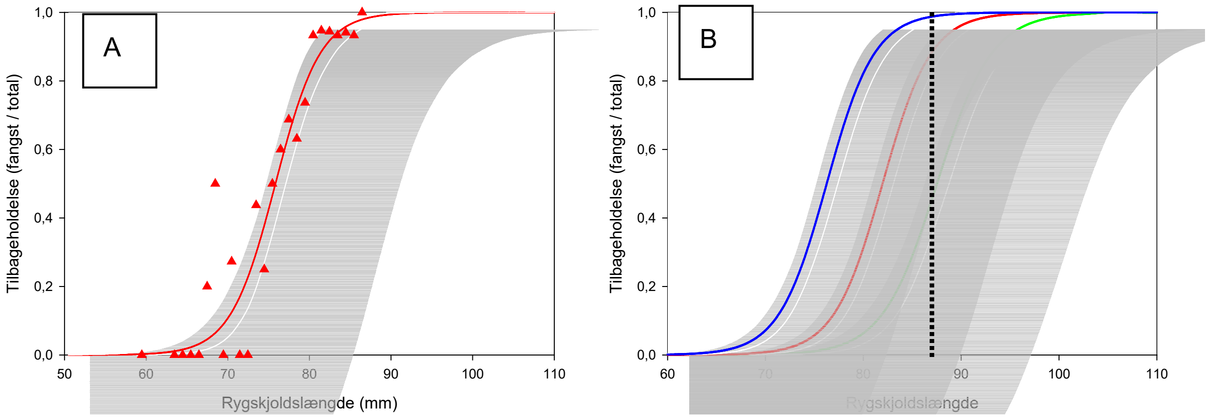
Figur 8.15. Tilbageholdelsen af hummer i redskabet med få (blå) og mange (rød) udslipshuller (De 3 kurver i hver farve indikerer middelværdien og 95% konfidensintervallet). Mindstemålet for hummer i Limfjorden er markeret med grøn. Der er overlap mellem konfidensbåndene for alle længdeklasser af hummer og der er derfor <u>ikke</u> signifikant forskel mellem de to redskaber.

Usikkerhed og forbehold

Hummerne blev udsat for ekstra håndtering idet de først blev fanget i tejner, håndteret, målt og genudsat i multitejnerne. Der er derfor en risiko for, at deres adfærd er påvirket af dette. Det store udslip af små hummere er imidlertid et klart bevis for, at hummerne opsøger og anvender disse muligheder for at slippe ud af redskabet og vi vurderer at dette også vil være tilfældet ved fiskerimæssig brug af redskabet.

8.5 Anbefalet dimension af udslipshullet

Et cirkulært udslipshul med en indvendig diameter på 60 mm vil effektivt kunne reducere bifangster af hummer under mindstemålet på 87 mm skjoldlængde, mens tabet af målshummer er lille.



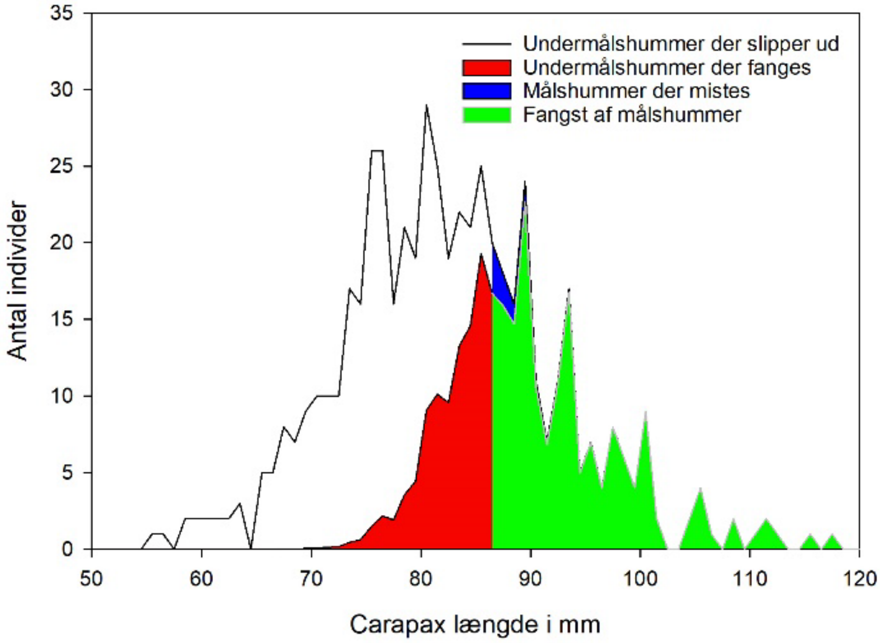
Figur 8.16. Panel A viser tilbageholdelsen af hummer i selektionsforsøget vist som datapunkter samt det beregnede gennemsnit med 95% konfidensbånd. Panel B viser modellens fremskrivning af selektion i redskaber med udslipshuller med indvendig diameter på hhv 55 (blå), 60 (rød) og 65 mm (grøn). Mindstemålet på 87 mm skjoldlængde er vist som en stiplet sort linje.

Begrundelse

I forsøget beskrevet ovenfor testede vi redskaber med cirkulære udslipshuller med en indvendig diameter på 55 mm. Data viser en tydelig længdeafhængig selektion hvor tilbageholdelsen af små hummer er meget lille, mens de store hummer ikke kan slippe ud af redskabet (Figur 8.16A). Forsøg i 2021 indikerede at 60 mm sandsynligvis ville være en passende diameter for et mindstemål på 87 mm. Men af hensyn til datastyrken, valgte vi at gå lidt ned i diameter, for at sikre at der var nok individer, der blev tilbageholdt. I kombination med forsøget fra 2021, tillader de indsamlede data beregning af selektionen i cirkulære udslipshuller med forskellig størrelse (Figur 8.16B). Resultatet er næsten identisk med det vi så i det tidligere forsøg, der alene tog højde for om hummerne rent fysisk kunne slippe gennem udslipshullerne (Fig. 8.8). Når der er tid til rådighed, er det med andre ord stort set alle hummer der vil benytte udslipshullet hvis de er små nok til at slippe igennem.

Effekten af at indsætte udslipshuller vil afhænge af størrelsesfordelingen af hummer i området. I et ekstremt tilfælde kan man forestille sig, at der i et område alene er hummer over mindstemålet, og her vil der ikke være en effekt af et udslipshul. For at synliggøre effekten af et udslipshul på landinger, discard og tab af hummer bruger vi størrelsesfordelingen af hummer fanget i den vestlige del af Limfjorden i juni 2022, i tejner uden udslipshuller. Hermed kan vi estimere, at, i det aktuelle fiskeri, kan udslipshuller med en diameter på hhv. 55 mm, 60 mm og 65 mm i gennemsnit reducere fangsterne af undermålshummer med hhv. 42, 72 og 92 %, mens det gennemsnitlige tab af målshummer er 0, 4, og 22%.

Ud fra en antagelse om, at en fiskeriindsats, med tilhørende forstyrrelse og brændstofforbrug, skal være effektiv, vurderer vi, at et 60 mm udslipshul rammer en god balance med et stort udslip af undermålshummer, kombineret med et lille tab af målshummer (Figur 8.17).



Figur 8.17. Estimerede fangster i en multitejne med 60 mm udslipshul. Hvis der ikke var udslipshuller ville alle hummer uanset størrelse blive fanget. Nu slipper alle hummer i det hvide felt ud. Det røde felt er undermålshummer, der stadig bliver tilbageholdt, mens det blå felt er målshummer, der slipper ud gennem udslipshullerne.

Som det ses af Figur 8.17 er risikoen for tab af målshummer begrænset til de mindste målshummer.

At en hummer kan passere gennem et udslipshul er ikke nødvendigvis ensbetydende med at den gør det. Dels kræver det tid for hummeren at lokalisere udslipshullet og dels er det muligt at hummeren ikke er villig til at passere en så snæver åbning. I England har forsøg med udslipshuller i hummertejner vist, at det er lykkedes at fjerne samtlige undermålshummer fra fangsten ved at indsætte rektangulære udslipshuller i siden af tejnen (Brown, 1982). Udover at beskytte undermålshummerne, havde tilstedeværelsen af udslipshuller en positiv effekt på fangsten af målhummer og dette forklares ved at tejnerne mættes (Brown, 1982). Når undermålshummerne kan slippe ud, er der således plads til flere målshummer.

8.6 Opsamling

Forsøgsfiskeriet

Landingerne i forsøgsfiskeriet lå på linje med hvad der er rapporteret som gennemsnit for perioden 2005-2019 (1,1 hummer pr. tre åleruser ved Venø i juni måned (Josianne Spøttrup, pers. com) og forsøget vurderes derfor at være repræsentativt for området.

Den store andel af undermålshummer i fangsterne var overraskende og fremhæver vigtigheden af at øge størrelsesselektionen i fiskeriet. De redskaber der anvendtes i forsøget, følger gældende lovgivning. Der er derfor ingen anordninger til at forbedre størrelsesselektionen af hummer og dermed reducere andelen af hummer under mindstemålet. Forsøg med andre arter af hummer har vist at tab af ben og/eller følehorn har en negativ indflydelse på hummerens vækst og overlevelse (Brouwer et al., 2006; Brown and Caputi, 1984; Emery et al., 2016). Der er ikke lavet tilsvarende forsøg med den europæiske hummer, men vi antager, at det også for denne art gælder at den energi der bruges på at regenerere lemmer, reducerer den samlede længdetilvækst. Da tab af lemmer både kan ske, mens hummeren er i redskabet og i forbindelse med håndtering på dækket, vil det være en fordel for tilvæksten i bestanden, hvis hummer under mindstemålet kan slippe ud af redskabet, mens dette stadig er i vandet. Fisk og kredsdyr, der fanges i garn og toggergarn, vil, i modsætning til hvis de fanges i åleruser, tejner eller multitejner, vikles ind i nylontråden og blive fastholdt. Udover at det tager længere tid at befri fangsten fra nettet, er specielt krebsdyr ofte viklet godt ind, hvilket øger risikoen for, at de mister ben eller klør, når de fjernes fra garnet. I nærværende forsøg har vi ikke undersøgt overlevelsen af genudsatte hummere.

Udslipshuller

Den store bifangst af hummer under mindstemålet vurderes at udsætte undermålshummerne for en unødvendig risiko i forbindelse med fangstprocessen og ved håndteringen. Det anbefales derfor at prioritere redskaber, hvor det er muligt at supplere redskabet med effektive udslipshuller. Dette er muligt og gennemtestet i hummertejner i vores nabolande og baseret på resultaterne fra dette projekt vurderes det også at være muligt både i åleruser og i multitejner. Ved et mindstemål på 87 mm rygskjoldlængde anbefales et cirkulært udslipshul med en diameter på 60 mm.

8.7 Referencer

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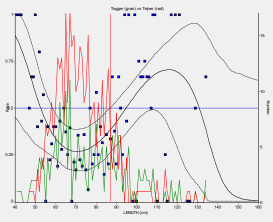
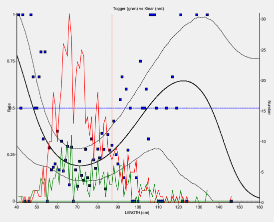
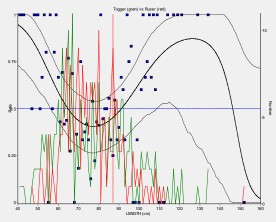
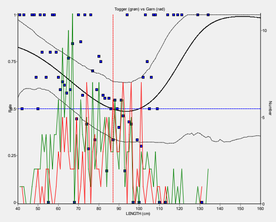
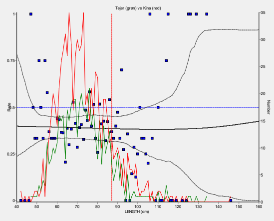
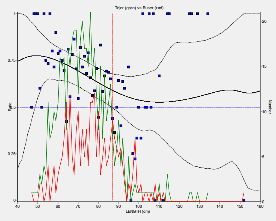
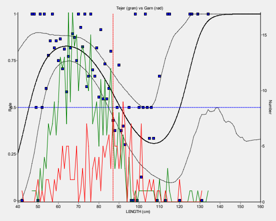
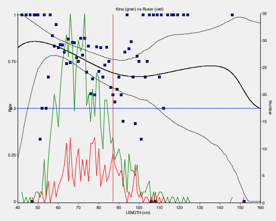
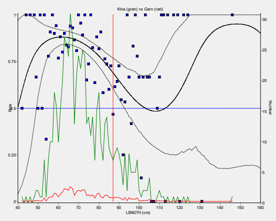
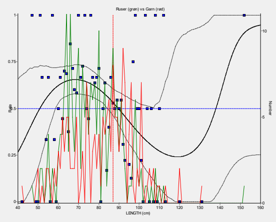
Kleiven, A., Moland, E., Sørdalen, T.J., Espeland, S.H., van der Meeren, G.I., 2017. Evaluering av effekten av forvaltningstiltak på hummer og forslag til tiltak. Rapp. fra Havforskningen 15–2017, 1–30.

8.8 Bilag A Data fra forsøgsfiskeriet

A.1. Sammenligning af fangsterne

Sammenligning af størrelsessammensætningen af de totale fangster i de forskellige redskaber. Den røde kurve viser størrelsessammensætningen i redskabet i kolonnen (markeret med rød) og mens den grønne kurve viser redskabet i rækken (markeret med grøn). De sorte kurver viser resultatet af dataanalysen inkl. 95% sikkerhedsintervallet. Hvis alle tre kurver ligger under den blå vandrette streg fisker redskabet i kolonnen færre hummer i de pågældende længdeklasser. Omvendt hvis alle tre kurver ligger over den blå streg.

	Tejner	Kina	Ruser	Garn
Togger				
Tejner				
Kina				
Ruser				

A.2. Fangst-ratio

		REDSKAB 2			
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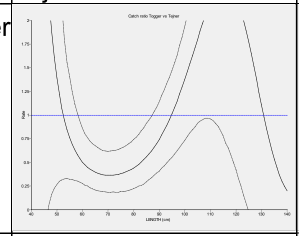
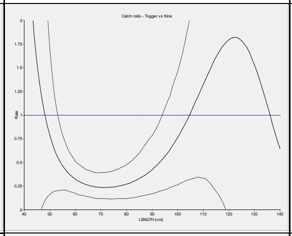
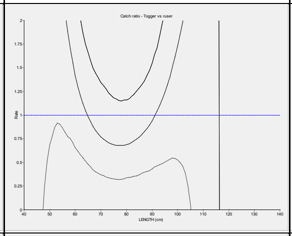
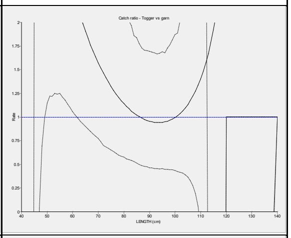
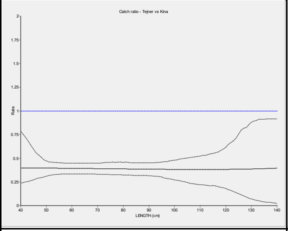
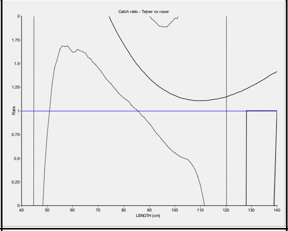
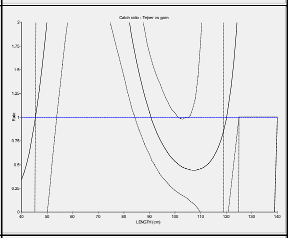
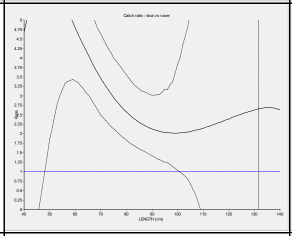
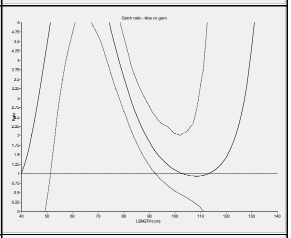
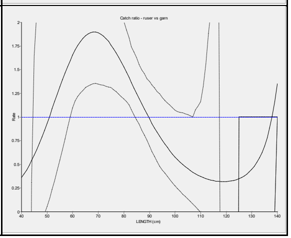
REDSKAB 1	Togger				
	Tejner				
	Kina				
	Ruser				

A.3. Kumuleret frekvens

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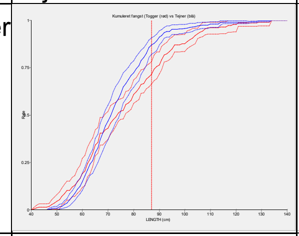
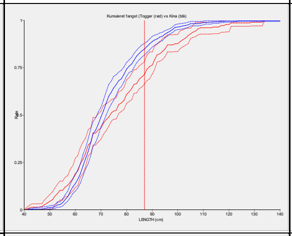
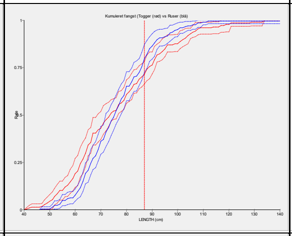
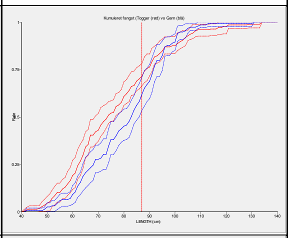
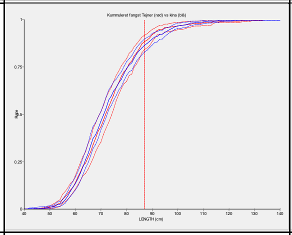
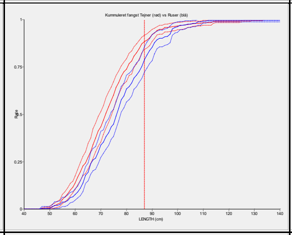
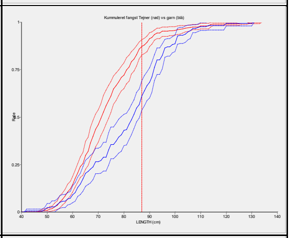
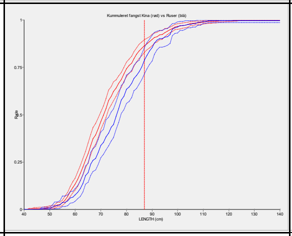
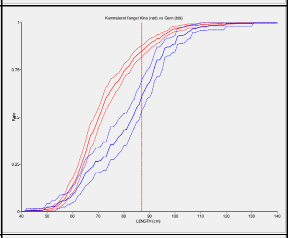
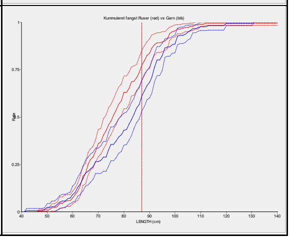
REDSKAB 1 (RØD)	Togger				
	Tejner				
	Kina				
	Ruser				

9. Recommendations to management

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9.1 Rationale

Landings of lobster (*Homarus gammarus*) in the Limfjorden have increased dramatically over the course of 10-15 years, with a consequent increase in the amount of gear in the estuary. Although there is no solid data supporting that the stock is threatened or that the fishing mortality is too high, there is on the other side no wish amongst stakeholders to reach a collapse of the population. Further, it has been suggested in several contexts that there is ongoing IUU (irregular, unreported and unregulated) fishing activity and lack of control that are additional threats to the Limfjorden lobster population.

There is thus a broad stakeholder wish for a management plan for the lobster fishery in the Limfjorden. In this context, it should be noted that lobster fishing in the Limfjorden is characterized by being very data-poor and there is therefore limited knowledge to support biological advice on which fishing pressure is sustainable in the long term. According to ICES guidelines, the lobster fishery in the Limfjorden can thus be described as a category 5 fishery, for which there is only landing data - and these are not complete for the lobster fishery in the Limfjorden - and very short data series for the fishing effort (ICES 2021). For this type of fishery, ICES recommends that "as information becomes more and more limited, more conservative reference points should be used and an additional margin of caution should be introduced when there is limited knowledge of the status of the stock". Finally, the wish for a management plan is also rooted in a general discussion about access to the estuary, environmental problems with ghost nets and how nature restoration projects such as the establishment of stone reefs or protected areas, and marine spatial planning, should be managed and possibly can be included in fisheries management.

9.2 Methods

DTU Aqua arranged a number of meetings with stakeholders both as open meetings for all interested parties and in an advisory steering group for the project with the participation of the Centralforeningen for Limfjorden (local section of DFPO, CF), The Danish Fishers Producent Organisation (DFPO), and Foreningen Skånsomt Kystfiskeri Producentorganisation (Sustainable Coastal Fishery Association, FSK-PO) as representatives of the commercial fishery, Dansk Fritidsfiskerforbund (Danish Leisure Fishery Association, DFF), Limfjordsrådet (The Limfjorden Council) and Fiskerikontrollen (Fisheries Control, FC). Based on project results, input from stakeholder meetings and association specific viewpoints, different recommendations were proposed and discussed. There has been a varying degree of support for these recommendations (see Table 9.1).

Table 9.1. Comments from stakeholders to DTU Aqua recommendations for improved management of the Limfjorden lobster fishery. Numbering in first column refers to recommendations in the text above.

Recommendation	DFPO	FSK	DFF	FC
General fisheries management				
No. 1	Supports	Supports	Supports	Supports
No. 2	Not interested in the implementation of other countries' regulations, but exclusively local conditions and sustainable utilization based on professional documentation	Supports	Supports	Supports
No. 3	In principle pro, but believes it will be impossible to implement in relation to other fisheries	Only with exceptions for commercial fishermen	Supports	If to be controllable, ban on deployment of all gear must be enforced just prior to 31/8
No. 4	Supports	Supports	In principle pro, but envisages problems in implementation	Supports but suggest implementing as ban of multi-pots in this fishery
Gear regulation				
No. 5	Commercial fishermen need to be able to use the gear that most effectively catches target species	Could be an option, but it requires proper implementation	Supports	Supports
No. 6	A working group in the Ministry is looking at it	Supports	Supports	A working group in the Ministry is looking at it
No. 7	Supports	Supports	Supports	Supports
Other management tools				
No. 8	No comments	Depends on the purpose	Supports	Supports
No. 9	Not in the commercial fisheries interest	Temporary closures can potentially be a good idea	Supports	Supports

The overall assessment of whether a specific recommendation is relevant is only an expression of DTU Aqua's assessment. It should further be noted that the suggested recommendations should only be understood as a supplement to existing regulation of the lobster fishery in the Limfjorden, which includes:

- Lobster in the Limfjorden is protected in the period 1st of July to 31st of August (both days included).
- Berried female lobsters are protected all year round.
- Minimum measurement for the total length of the carapace must be at least 87 mm.
- Protected lobsters and lobsters under the minimum size may not be kept on board or brought ashore and should be released immediately.
- In the Limfjorden, fyke nets must be fitted with either a permanently installed escape vent or other means to prevent undesired capture of marine birds and mammals (otters).

DTU Aqua has not made an independent assessment of the existing management. However, DTU Aqua would like to draw attention to the fact that with more data on the time of release of eggs, mating and spawning, there could be a basis for an evaluation of whether the choice of a closed period is optimal. For instance, at the beginning of June, a high number of soft-shelled hummers are reported, and mating can begin. The trade-offs of a shift to an earlier start of the closed period would be higher catches in late August (higher temperature) and potential catch of females that may not yet have released eggs.

It should also be noted that among the participating interest organizations there is a wish for increased fisheries control in the Limfjorden regarding the lobster fishery.

9.3 Results

Recommendations for additional management are divided into categories:

General fisheries management

1. Only whole lobsters can be landed - landing only tails or claws must be prohibited. The proposal is based on a wish to reduce the possibility of cheating with the minimum size or protection of berried females. Furthermore, tearing off claws and tails can be considered both unnecessary animal cruelty and a waste of resources. It must also be emphasized that at EU level there are recommendations to prohibit the landing of parts of lobsters. The proposal is easy to implement and control.

2. Harmonization of rules for conservation (berried females, minimum size, closed periods) between the Limfjorden and adjacent fishery areas. The proposal is based on the desire to limit cheating with the conservation regulations in the Limfjorden by landing lobsters caught in the Limfjorden in harbours outside the Limfjorden without proper landing records. The existing protection conditions for minimum size, protection period and ban on landing of berried females will help to prevent inappropriate fishing and conflicts with similar regulations in other European countries as well as the USA and Canada. EU legislation introduced a minimum protection size of 87 mm carapace length for European lobster fished in the North Sea and North-Western waters (EC Technical Conservation Regulation No 850/1998; replaced by Regulation 2019/1241), but with a carapace length of 78 mm or 220 mm total length for Skagerrak/Kattegat. It also implemented the commitment to keep on board and land only whole lobsters. In this recommendation, no decision has been taken as to whether a harmonization of the minimum size between areas should be based on the regulation in the Limfjorden, the North Sea or the Kattegat/Skagerrak, which would require an assessment of size at onset of maturity. The proposal can be easily implemented and controlled.

3. Do not allow gear to be deployed before the fishing season begins. Today, the protection period is effectively a landing ban, not a ban on deployment of fishing gear, the implication being that already at the beginning of August gear is deployed on a large scale in suitable locations. Regardless of whether the purpose of deploying gear is to reserve space and the gear is regularly emptied, or whether illegal landings are taking place, gear placed in the Limfjorden will increase fishing mortality during a critical period when the stock has just been protected to reduce fishing mortality and protect moulting lobsters. There are some control challenges when implementing this proposal, which could also have an impact on fishing for species other than lobster during the period when lobster fishing is closed.

4. Regulation of landings in the recreational fishery. There is a limit to how many lobsters one can consume as a recreational fisherman for private consumption. A maximum allowed catch could contribute to a reduction in unregistered landings and illegal sales and would – although recreational fishing probably contributes a small fraction of total fishing mortality – reduce the pressure on the stock. An accompanying reporting obligation will contribute information to an already data-poor fishery. Implementation of the proposal will require some consideration of implementation. Several models can be considered, including gear regulation, so that recreational fishermen are not allowed to use e.g., certain gear types. The alternative is a limit on maximum landings per time unit, such as day or week, for which the administration can draw on experience from other recreational fishing with reporting obligations.

Gear regulation

5. Ban on the use of gill nets in the lobster fishery. There is a general wish among all stakeholders to ban the use of gill nets in the lobster fishery in the Limfjorden. The stakeholders' wish derives from the view that nets cause damage to lobsters, which makes it more difficult to successfully restock lobsters below the minimum size. In experiments, DTU Aqua has not been able to conclude anything definitive about the importance of tools for injuries and survival, but it can be assumed that the handling of gear by the individual fisherman will be important for the extent of injuries. In relation to the use of nets in fishing, there are also major problems in the Limfjorden with the occurrence of ghost nets, which largely originate from the lobster fishery. There are various possible proposals for the implementation of a ban on the use of gill nets, which can be done by periodic bans on the use of nets (e.g. 1/5 – 1/11) or by a general ban on nets in geographically defined areas (e.g. east-west from Aggersund Bridge to Thyborøn and south-north from Hvalpsund to Amtoft). A ban of gill nets will potentially affect a flatfish fishery in the Limfjorden, but such fishery is currently largely non-existent in the areas where many lobsters are fished. It should be considered to introduce a "sunset clause", in view of potential future development, on a ban of gill nets if there were again many (edible) fish (and fewer lobsters) in the central parts of the Limfjorden.

6. Clear definitions of the dimensions of multi-pots as an independent gear type. Lobsters can be fished with different gear types like gill nets, trammel nets, fyke nets and pots. Multi-pots ("kinaruser") are not in this context considered as an independent gear type. Consequently, there are different versions of the gear type on the market. A clear definition of the gear type with a maximum length of e.g. 10 m could ease control and is in general recommended by the stakeholders. In this context, DTU Aqua would like to draw attention to the fact that multi-pots are probably the most used tool in the Limfjorden fishery today, together with fyke nets. If restrictions on the number of gears are introduced in the commercial fishery as well, a definition of multi-pots can help to reduce fishing mortality. The proposal can be easily implemented and controlled.

7. Escape vents in pots, fyke nets and multi-pots must be mandatory. Escape vents will ensure that undersized lobsters can escape the gear and thus the mortality rate and discards will decrease, because the escaped lobsters will not perish or be damaged during handling, or if the gear is filled with more lobsters or crabs. Escape vents will also contribute to the real conservation of undersized lobsters, including helping to maintain the ban on landing undersized lobsters. The number of escape vents must depend on the gear type and its size, but there may be several vents in the same gear. The size of the escape vents will depend on the minimum size of the lobster. The proposal can be easily implemented and controlled.

Other management tools

8. Data collection programs are initiated. Efficient management requires knowledge. There is very little information about the lobster population in the Limfjorden as well as on fishing mortality. There is thus a lack of basic information on the number of boats in the fishery, fishing days and number of gears deployed, which applies to both commercial and recreational fishery. It is common knowledge among the active fishermen that official landings do not represent actual landings. In reality, there is thus no reliable data that can support quantitative interventions such as limiting landings or fishery effort in the form of e.g. number of commercial licences, number of gear or fishing days or interventions regarding the minimum and maximum size of landed lobsters. Suggested efforts include catch reports on selected vessels in different sub-areas of the Limfjorden, development of knowledge about biological characteristics of the stock through systematic data collection by DTU Aqua without, however, necessarily to the full extent of providing stock estimates. It is considered that these proposals can be easily implemented.

9. Closure of areas to fishery. Marine protected areas are used in other countries to ensure a spawning population. DTU Aqua has documented in the project that lobsters migrate over greater distances (several km) in the Limfjorden, but there is also data that suggests that there are larger lobsters in and around the protected area at the recently constructed stone reef in Løgstør Bredning, that can support the hypothesis that a marine protected area can be a starting point for recruitment because fecundity increases with the size of female lobsters. Furthermore, it has been argued that habitats such as re-established stone reefs must be protected against fishing i.e., because they are established to ensure biodiversity. No decision has been taken here on criteria for potential protected areas. Should it e.g. apply to existing stone reefs, should there be a requirement for distance to other protected areas or should it be based on areas where there is high fishing pressure? Use of the closure of areas for fishing must thus be accompanied by studies or the establishment of criteria that can ensure that the intentions of the protection measures are fulfilled. Protection of areas can be easily implemented and controlled.

9.4 Final remarks

Management of fisheries usually includes tools such as quotas for maximum catches or limitations to the number of gears as a regulation of fishing pressure or licensing schemes that limit access to the fishery to thereby reduce fishing pressure. DTU Aqua does not currently have the scientific basis to be able to advise on specific quotas, let alone the most sustainable fishing pressure. It is possible that in time, it will be necessary to make a regulation that limits the fishing mortality more directly than the recommended management tools, but in that case, it should be science based, which will require further data collection. A first step could be that systematic accounts are made of catches in different fishing areas, e.g. through DTU Aqua's participation in fishing trips.

DTU Aqua also does not consider it currently documented that a maximum size for landed lobsters – based on assumptions about the relatively greater fecundity of large female lobsters – will have a documented effect in the Limfjorden at present. An upper limit of approx. 120 mm length of the carapace, as is known from other European countries, would only protect less than 0.2% of the female lobster stock in the Limfjorden in 2022 (Chapter 4, this report).

The above-described recommendations are entirely DTU Aqua's and the stakeholders in the open meetings or in the project advisory board cannot be held responsible for them. Stakeholders have provided important contributions to the recommendations and their experience have been improved the recommendations. However, different stakeholders have not agreed in all the recommendations. In Table 9.1, stakeholder comments to the recommendations have been summarized.

9.5 Reference

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