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Executive summary

The Working Group on Crangon Fisheries and Life History (WGCRAN) meeting was held at ICES Headquarters, Copenhagen, Denmark, 9–11 October 2018. Members of WGCRAN see the priority of this expert group in understanding population dynamics and factors influencing the stock and the individual. A central goal is to establish a biological basis for advice and to identify suitable ways for sustainable management.

Stock status indicators from surveys (DFS, DYFS) were generated including biomass swept-area estimates, estimates on total mortality and large shrimp indicators. Fishing effort was further standardized among countries, now taking into account a higher accuracy for Dutch data. Processing of landings data (e.g. nation-dependent conversion factors from cooked to fresh weight) was discussed and should be addressed in the future.

Landings during the last decades increased resulting in a peak in 2005, and showing similar levels afterwards. From 2015 to 2017, landings steadily decreased resulting in values for 2017 which are comparable with those of the 1980s. The time-series of effort peaked in 2016, but was markedly reduced in 2017. Standardized landings per unit effort (LPUEs) for the bulk of the fleet (Dutch, German and Danish) were lower during 2016 and 2017 compared to the last decade. The mean share of shrimp > 60 mm showed a moderately increasing trend in recent decades. However, the last years values were different: in the DFS survey the fractions of large shrimp were exceptionally low in 2015–2017. Total brown shrimp abundances measured in the DYFS in 2016 and 2017 were almost the lowest in the time-series. Corresponding to that, biomass production values for the last three years show a decline compared to 2013. Total mortality was slightly decreasing during the last years (to 4.7 y^{-1} in 2017). A strong pressure of the fishery on the stock as well as a high abundance of whiting as predator documented during the surveys have been the reason for the low stock size.

Beginning in 2016, the industry self-management came into force regulating the bulk of the fleet (~80%). Major actions were a stepwise increase in mesh size to reduce growth overfishing and a harvest control rule (HCR) to prevent recruitment overfishing. In 2016, mandatory mesh opening was 20 mm (mean of the fleet before 2016) and mesh size in action at the end of 2017 was 22 mm. Positive effects on landings as predicted by two independent models were hard to document in the real world because of high fluctuations in recruitment levels. It was debated whether under constant recruitment conditions, catches will actually increase since density dependent growth effects might counteract. However, a biomass increase associated with a mesh size increase is actually minor when compared to the differences between years with good and poor recruitment. Additionally, analysis of size distributions from surveys could not find any evidence for the share of large shrimp decreasing with increasing biomass. Concerning the HCR, the reproduction of reference values as well as monthly LPUEs used by the industry was not possible, indicating that the fishery needs to establish a standardized protocol. The current level of reference values is probably too low as the HCR kicked only in 2 times in 2016, a year with extreme low stock size and high fishing effort. When calculating the monthly LPUE, fishermen which stop fishing (e.g. due to low stock abundance like 2016) should be accounted for. Furthermore, a spatial component should be included to the

HCR in order to prevent additionally fishing mortality in areas with low shrimp abundance.

1 Administrative details

Working Group name

Working Group on Crangon Fisheries and Life History (WGCRAN)

Year of Appointment within current cycle

2016

Reporting year within current cycle (1, 2 or 3)

3

Chair(s)

Josien Steenbergen, the Netherlands

Meeting venue(s) and dates

23–25 May 2016, Oostende, Belgium (10 participants)

7–9 November 2017, Hamburg, Germany (12 participants)

9–11 October 2018, Copenhagen, Denmark (11 participants)

2 Terms of Reference

a) Report and evaluate population status indicators like recent landings and effort trends in the brown shrimp fisheries or length based mortality estimates from Dutch and German scientific surveys. Generate a standardized LPUE time-series of higher accuracy for the Netherlands with horse power days calculated based on hours at sea. Investigate methods to gain a better understanding of the recruitment processes and density dependence. (Lead persons: all group members);

b) Combine VMS, landings and effort data to gain a population distribution indicator and to monitor regional distribution and regional shifts in fishing effort. Evaluate the variability of the results by comparing different VMS data interpolation methods. (Lead persons: Katharina Schulte, Torsten Schulze);

c) Develop brown shrimp specific management decision support tools to evaluate strategies on how to sustainable and efficiently harvest the brown shrimp stock (Lead persons: Axel Temming);

d) Analyze and enumerate the effects of new gears (e.g. pulsetrawl, combined pulse-trawl and standard gears, large or new mesh types, pumpsystem, letterbox etc.) and their implications on the Crangon stock, the bycatch, the catch efficiency and the possible LPUE based management strategies (Lead persons: Bart Verschueren, Josien Steenbergen);

e) Analyze and evaluate possible methods to assess and manage the brown shrimp fisheries in the ICES region. Gather, compile and evaluate information on the onboard and ashore sieving fractions and processes and new national by-catch/discards data from e.g. DCF (Lead persons: Josien Steenbergen, Axel Temming);
f) Analyzing infection levels with bacilliform viruses and/or the occurrence of other diseases and determining the potential effects they might have on the population (Lead persons: Benigna van Eynde);
g) Determining the potential on using brown shrimp as a species for use in aquaculture system. Improvement on how to rear and grow shrimps in the lab and to obtain "in-situ", real field growth rates for comparison (Benigna van Eynde, Marc Hufnagl, Axel Temming);
h) Optimize and harmonize German and Dutch surveys to improve comparability, to analyze spatio-temproal trends of stock indicators (biomass, distribution, mortality, etc.) and to ground-truth VMS derived LPUE estimates. (Lead persons: Holger Haslob, Ingrid Tulp);
i) Exchange of information on national legislation, laws (e.g. concerning Natura 2000) and developments (MSC process) concerning the brown shrimp fisheries in the whole North Sea for an improved cooperation and coordination of research and advice efforts. Presentations on developments and ongoing brown shrimp research in the ICES area. (Lead persons: all members).

3 Summary of Work plan

Year 1	Stock status indicators (ToR a) shall be udated and harmonized between countries. Data for Manuscripts related to ToR b-d and f-g shall be available New hauls to be included in the analysis under ToR h shall be available New information from ToR I shall be reported
Year 2	Stock status indicators (ToR a) shall be udated and harmonized between countries. Data for Manuscripts related to ToR b-d and f-g shall be analyzed New hauls to be included in the analysis under ToR h shall be available New information from ToR I shall be reported
Year 3	Stock status indicators (ToR a) shall be udated and harmonized between countries. Manuscripts related to ToR b-d and f-g shall be submitted New hauls to be included in the analysis under ToR h shall be available New information from ToR I shall be reported

4 Summary of Achievements of the WG during 3-year term

a) Stock status indicators

I. Indicators were updated yearly (see section 5)

II. Standardized LPUE time-series of higher accuracy for the Netherlands with horse power days based on hours at sea

III. ***Paper:*** Ingrid Tulp, Chen Chun, Holger Haslob, Katharina Schulte, Volker Siegel, Josien Steenbergen, Axel Temming & Marc Hufnagl (2016). Annual brown shrimp *Crangon crangon* biomass production in NW Europe contrasted to annual landings. ICES journal doi:10.1093/icesjms/fsw141.

b) Combine VMS , landings and Effort data

I. ***Dissertation*:** The monitoring of the spatiotemporal distribution and movement of brown shrimp (*Crangon crangon* L.) using commercial and scientific research data

II. ***Paper***: Schulte, K. F., Dänhardt, A., Temming, A., Hufnagl, M., Wosniok, W. (2018). Not easy to catch: multiple covariates influence catch rates of brown shrimp (*Crangon crangon* L.), potentially affecting inferences drawn from catch and landings data. ICES Journal of Marine Science 75(4): 1318-1328.

c) Brown shrimp specific management decision support tools

I. ***Project Report***: Steenbergen, J., Kooten, T. van, Wolfshaar, K. van de, Trapman B., Reijden, K., van der., 2015. Management options for brown shrimp (*Crangon crangon*) fisheries in the North Sea. Imares report C181/15 (https://edepot.wur.nl/366175).

II. ***Report*:** Georg Respondek, Margarethe Nowicki, Claudia Günther, Axel Temming. Scientific guidance and consulting for the brown shrimp management plan during the MSC-certification process – Part II. Final Report. Hamburg, Institute of Marine Ecosystem and Fishery Science (IMF), June 2018.

III. ***Paper***: Steenbergen, J., Trapman, B.K., Steins, N.A., Poos, J.J., 2017. The commons tragedy in the North Sea brown shrimp fishery: how horizontal institutional interactions inhibit a self-governance structure, ICES Journal of Marine Science, Volume 74, Issue 7, Pages 2004–2011, https://doi.org/10.1093/icesjms/fsx053.

IV. ***Paper*:** Temming A, Günther C, Rückert C, Hufnagl M (2017) Understanding the life cycle of North Sea brown shrimp *Crangon crangon*: a simulation model approach. Mar Ecol Prog Ser 584:119-143. https://doi.org/10.3354/meps12325

d) Effects of new gears

I. ***Presentation*:** Ongoing research project investigating the catch and bycatch of shrimp pulse fisheries in the Netherlands.

e) Possible methods to assess and manage the brown shrimp fisheries

I. *Report*: Claudia Günther and Axel Temming. Scientific guidance and consulting for the brown shrimp management plan during the MSC-certification process – Part I. Final Report. Hamburg, Institute of Hydrobiology and Fishery Science (IMF), June 2017.

II. *Master thesis:* Anne Bönisch (2017). The survival rate of undersized shrimp *Crangon crangon* after catch with a commercial bottom trawl in the German Wadden Sea. University of Bremen.

f) Infection levels with bacilliform viruses and/or the occurrence of other diseases

I. ***No new update:*** Persons involved in the research did not join the meeting

g) Potential on using brown shrimp as a species for use in aquaculture system

I. ***Presentation:*** Update of new growth experiments was provided (part of ToR i)

h) Optimize and harmonize German and Dutch surveys

I. Abundance indices of two overlapping sampling areas (405 and 406) were compared

i) Exchange of information

I. Danish research project

II. Ongoing experimental research in the University of Hamburg

III. Project: Cranimpact

IV. Project: Cranman

5 Final report on ToRs, workplan and Science Implementation Plan

5.1 ToR a) Stock status indicators

General development and overview

The total number of vessels targeting brown shrimp in the North Sea during 2015 were about 550, from this total, 198 were German, 202 were Dutch, 27 were Danish, 29 were Belgian, 40 were French and 54 were UK shrimpers. As numbers have not been updated during the last years for all countries, and concerning difficulties in obtaining information on numbers of, e.g., smaller ships, these figures may be uncertain. Since 1960 total yearly landings of brown shrimp increased with a peak of 38 628 tons in 2005. Since then yearly landings varied between 22 077 (2017) and 37 321 (2014) tons. Yearly landings have decreased for the third year in a row 2015–2017, and were in 2017 comparable with those of the 1980s.

Total North Sea yearly effort between 2007 and 2016 (for 2017 figures were not reported for all countries) varied on a level of 30 000 000 horse power days at sea (hp-das). The highest total yearly effort was about 40 000 000 hp-das in 2016. In 2017, the effort figures for the countries, which provided such, indicate a marked effort decrease compared to preceding years. Concerning standardized landings per unit effort (LPUE) based on hp-das, these were lower during 2016 and 2017 compared to the mean for 2008–2017 for

Germany, Netherlands, and Denmark, but not clearly lower for Belgium and France (no information was available from UK).

In 2017, a standardized LPUE time-series of higher accuracy for the Netherlands with horse power days calculated based on hours at sea was generated for the data from 2010 onwards. The UK data has been adjusted for exact hours at sea, or 24 hrs per whole day absent, or 12 hours for a day trip. For France two sets of data have been provided: shrimp landings and effort in France as a whole (France total) as well as French landings and effort within the North Sea (ICES areas IV and VIId). In this report French landings and effort within the North Sea (ICES areas IV and VIId) is reported.

Landing statistics 2017

In 2017, a total of 22 077 tons brown shrimp (*Crangon crangon*) was landed in the North Sea, the third year in a row with decreasing total catches after 2014. Before 2016, the last time when less than 30 000 tonnes were landed was in 2002 (Figure 7).

Especially in Germany, landings were considerably lower in 2016 and 2017 compared to the preceeding decade. The German share of the total landings has gradualy decreased since approximately 2005, to about 33% in 2017 (Figure 1). Looking at the monthtly landings especially spring deviates; where there was normally a peak in landings during spring, however, this was not the case in 2016 and 2017 (Figure 8a) The patterns observed for the German shrimp landings in autumn were higher in 2017 when compared to 2016. Fishing effort was higher in spring than the year before for both 2016 and 2017, and also higher during summer in 2017 compared to the 10-year mean (Figure 9a, 10a). As one can expect the LPUE's (catches per unit effort) where also considerably lower in 2016 and 2017 when compared to the average (Figure 11a). Dutch shrimp landings peaked in 2014 and decreased afterwards. In 2017, landings were back to the levels of the late 1990s (Figure 2). The share of Dutch landings out of the total landings (whole North Sea, all nations) was above 50% in 2017 (Figure 2). Seasonal landings (Figure 8a) and effort data (Figure 9a, 10a) were lower throughout the year compared to the average, with a peak in landings and LPUE (Figure 11a) in autumn. However, the Dutch effort was higher in 2016 and 2017 compared to the 10-year average (Figure 9a, Figure 10a). Clearly, the abundances of shrimp were lower in 2016–2017 in the German and Dutch coastal waters.

The Danish total catches were also less in 2016 and 2017 compared previous years (Figure 3), these patterns were also observed in lower seasonal landings (Figure 8a). Overall a lower LPUE was observed througout the year in 2017 (Figure 11a). The Danish seasonal efforts in 2017, were close to the long-term averages (Figure 9a, Figure 10a). The landings in Belgium (Figure 4) and France (Figure 5) have varied between years since 2000 but were during the latest three years not as negative compared with the landings by Germany, Netherlands and Denmark. For UK, the trend in landings after a peak year in 2001 has been decreasing (Figure 6). However as the shares of landings from Belgium, France and UK are between 0.2–4% out of the total, their landings did not significantly affect the total amount. The seasonal landings for Belgium show a strong peak in autumn, at which the landings for 2016 were higher and the landings for 2017 were lower than for the long-term average (Figure 8b). Higher landings in the autumn were also true for France in 2016, while in 2017 French landings were below average in the autumn (Figure 8b). For UK, which also has a peak in seasonal landings during autumn, the autumnal peak in 2016 was also higher than the long-term average (Figure *8*b; data for 2017 is lacking). For

Belgium, the seasonal LPUE also peak in the autumn, where the LPUE for 2016 and 2017 have been close to the long-term average (Figure 11b). For France, the seasonal LPUE is more variable, also for 2016 and 2017 (Figure 11b). For UK, the seasonal LPUE seems more homogenous throughout the year, and there was a strong peak in LPUE in November in 2016 which otherwise showed lower LPUE compared to the long-term average (Figure 11b; data for UK 2017 is lacking).

Fraction of large shrimps

The fraction of shrimps > 60 mm caught in the different surveys conducted during autumn showed a decreasing trend over time until about 1990 (Figure 12). However the decreasing overall trends may partly be explained by different periods of bycatch (Busum and Ost-Friesland) and survey (DFS and DYFS) time-series taking place over the included time period. Both bycatch series decline from the start in 1955 until the 1980s whereafter the percentage of shrimp > 70 mm stabilises. The share of shrimps > 60 mm shows a moderately increasing trend in recent decades, during which it varies from 10 to 25% (Figure 12). In the DFS survey, the fractions of large shrimp were exceptionally low during 2015–2017.

Mortality

After a continuous increase in total annual mortality (Z) during 1955–1995, there has been strong annual variations. From 1994, there was a decreasing trend until 2008, and thereafter no clear long-term increase or decrease (Figure 13, methods see Hufnagl *et al.* (2010)). However, after 2013 the mean annual total mortality (Z) showed a decreasing trend and was about 4.7 y^{-1} in 2017.

Biomass production/swept area estimate

An area swept biomass index of *Crangon crangon* combining the Dutch DFS and German DYFS was constructed in order to contrast the results with annual landings data. This work was published in the ICES Journal of Marine Science (Tulp *et al.* 2016). The index was updated during the last WGCRAN report in 2018.

In Tulp *et al.* (2016), total biomass production was calculated based on a swept area estimate of brown shrimp. In this report we only update the swept area estimate (Figure 14), not the full biomass production estimate (that takes P/B ratio into account based on the mortality estimate). The value for the last three years shows a decline compared to 2013.

Area specific trend in brown shrimp and whiting

The area specific trends of brown shrimp was compared to those for whiting for ICES areas (Figure 15).

In 2016 and 2017 the *Crangon crangon* abundances were amongst the lowest in the time-series. The survey data show that this might be linked to the high abundances of whiting which were also recorded in these years (Figure 16). The group concluded that predation by whiting was one of the reasons for the low *Crangon crangon* stock, but that other bottom up processes, which are not well investigated and understood so far, also contributed to the historical low *Crangon crangon* abundances.

Science Highlights

Commercial landings and effort data are important indicators that give insights into the long term development, interannual variation and seasonal patterns. Fishery independent data such as the German Demersal Young Fish Survey (DYFS) and the Dutch Demersal Fish Survery (DFS), both conducted mainly in the autumn, provide valuable insights concerning the spatial distributions of shrimps as well as external drivers that may influence the population dynamics including size structure and the number of fecund females. Size distributions obtained from the surveys can be used to estimate total mortality rates as well as to provide size-based indices such as the fraction of large shrimps in the populations. Being highly standardized, the catch per unit effort (CPUE) from surveys can be used to estimate swept area biomass.

5.2 Tor b) Combine VMS, effort and landings data

Combine VMS, landings and effort data to gain a population distribution

This task was delt with by Katharina Schulte (Schulte 2015; http://ediss.sub.uni-hamburg.de/volltexte/2016/7938/pdf/Dissertation.pdf). For the years 2007–2013 data of the German fleet were used to analyse the logbook, landings and VMS information of 226 vessels. By using all vessels recorded in the data base a "mean vessel" was defined, and all LPUEs were standardised to the LPUEs this "mean vessel" would have reached. In a next step the expected ln(LPUE) for the mean vessel were calculated. This expected ln(LPUE) is attained by a mean vessel under mean conditions of year, month, depth and other vessel- independent factors. In 2018 the work was also published in the ICES journal of Marine Science (Schulte *et al.*, 2018).

Combine VMS, landings and effort data to monitor regional distribution and regional shifts in fishing effort

A straightforward approach to calculate the distribution of fishing effort is to use the ICES database gained from the OSPAR-HELCOM VMS data call. In the set of data all effort is document by own c-square level and by metier level 6 (TBB_16-31_CRU identifies the beam trawlers targeting brown shrimp). It needs to be solved with ICES if the dataset can be used to produce maps and other output. Analyses with this data set are recommended for the future.

Changes/ Edits/ Additions to ToR

The part "compare different VMS data interpolation methods" is also delt with by Katharina Schulte (Schulte 2015; http://ediss.sub.uni-hamburg.de/volltexte/2016/7938/pdf/Dissertation.pdf). However, these analyses do not address the overall focus of WGCRAN, but might be useful in the context of WGSFD.

Cooperation with other WG

WGSFD - preferably

Science Highlights

Significant steps are made on how to use the LPUE's as an indicator for the population distribution. This in the end can be used for management purposes.

5.3 ToR c) Brown shrimp specific management decision support tools

Together with the Brown Shrimp Cooperative MSC Group, the University of Hamburg conducted a follow up research and development project aiming at the real world implementation of the proposed management strategy to achieve a sustainable use of the brown shrimp stocks in the North Sea within the framework of the MSC certification. The project (title: "Scientific guidance of the brown shrimp MSC certification process") was conducted at the IHF, Department of Biology, of the Faculty of Mathematics, Informatics and Natural Sciences in the period from 1 July 2017 – 30 June 2018 (12 months) under the supervision of Prof. Dr. Axel Temming. The results will published in form of a report to the MSC Steering Committee and are summarized below.

Study possible density dependence effects by analysis of survey and commercial LPUE

The seasonal data from the sieving stations could potentially be used to deduce the growth rates of adult shrimp between late summer and late autumn. In case of the sieving stations data, not all vessels are included, but for the years 2014–2017 the exact sieve information (6.8, 8.5 and 9.5 mm) is available. Preliminary analysis confirms the high rates as used in the population simulation model of Temming *et al.* (2017).

Size distributions of experimental brown shrimp catches, are available from two long time-series for a single season, autumn: from the German Demersal Young Fish Survey (DYFS) and the Dutch Demersal Fish Survey (DFS). An analysis of length frequency distributions (LFD) from German and Dutch scientific surveys with a 20 mm cod end revealed a high variability between regions within the same year. This makes a comparison of commercial LFD from larger meshes and these scientific LFD meaningless as a method to detect the improved selectivity, given the small differences in the mesh sizes.

To investigate a potential effect of population density on the size structure of the brown shrimp stock, we compared the share of a large length class (60–70 mm) in relation to that of the next smaller length class (50–60 mm). If growth is affected negatively, one would expect a smaller share of the large size class in years with high stock densities. Figure 17 shows the ratio as a percentage of the abundance of the 60–70 mm length class relative to the abundance of the 50–60 mm length class for all sub-areas and years plotted over the mean shrimp density (mean number of individuals fished per 15 min). There is no clear pattern visible, although the shrimp density varies by a factor of 3 between years. This natural variability in density is substantially larger than the biomass increase predicted by the simulation model following an increase of the mesh sizes from 20 to 26 mm. Figure 18 shows the percentage of the abundance of the 60–70 mm length class relative to the abundance of the 50–60 mm length class as one mean value over all subareas. The pattern is essentially the same as in Figure 17: in spite of huge differences in overall density the share of the large size class relative to the smaller size class is highly variable but without a clear relationship to density.

For a comparison of the scientific survey estimates of shrimp density with commercial LPUE data the mean landings per unit effort (LPUE) of the commercial fleet was calculated for the same squares as sampled by the DYFS, in each year as a mean of September and October. In addition, the percentage share of the two size categories of HCN 1 and HCN 2 out of the landing declaration data was calculated as a mean of the both months (September and October) for every year. The catch numbers from the DYFS were converted into catch weight of the commercial fraction (> 6.8 mm CW) per hour. Figure 19 shows the commercial LPUE values plotted against the corresponding catch weight of the commercial-sized shrimp from the DYFS data of the same area and year. While there is a general positive correlation the data show a wide scatter and also some systematic bias. In ICES 38F8 the survey tends to underestimate the commercial LPUE, probably due to an offset between the survey and the commercial fishing positions. The opposite bias exists for the ICES area 36F7. It can be noted that the regression line does not intercept at the origin, which implies, that the commercial LPUE overestimates the true density in years with low shrimp biomass. If the data are averaged for the whole year the scatter is much reduced, but the pattern is similar with a positive intercept (Figure 20). The factor relating both density values is 8.6 at a density of 40 kg/h (DYFS) but increases to 15 at the low density level of 10 kg/h (DYFS) as observed in the years 2007 and 2016. This points at a risk of overestimating the true density especially in poor years.

Model effect – increase mesh size and effort reduction on LPUE/F

Model runs were performed to compare the effects of mesh size increases (Figure 21, Figure 22) and effort reductions (Figure 21, Figure 23) as alternative management options. For the same increase in landings as expected by a mesh size increase from 22 to 24 or 26 mm, fishing mortality/effort has to be reduced by 13 or 23%, respectively. Following this reduction in effort, biomass of the shrimp stock would strongly increase by 23 or 46% in contrast to a moderate increase which is expected with a mesh size increase (10 or 24%). The stronger increase in biomass may be relevant, if density dependent effects on growth rate are strong enough to counteract the catch gains resulting from decreased mortalities (Figure 24). German logbook data of 2016 were analyzed to estimate the amount of effort spent on weekends; 23 or 30% of the effort took place from Saturday to Sunday or Friday to Sunday, respectively. Thus, the effort reduction which would be necessary in order to compensate for the keeping the mesh size at 22 mm could be achieved for the German fleet by a weekend closure, but only if effort is not shifted to the week.

Harmonize LPUE registration & find out what is actually in the logbooks

For the self-management of the Brown shrimp fishery in 2016, a steering committee calculated the monthly LPUE from data submitted by the producer organizations (PO). This value is then compared to the reference values which are written down in the management plan. These reference values (Ref1 to Ref 5) are calculated as 70%, 65%, 60%, 55% and 50% of the mean monthly LPUE of 2002 and 2007. No description is given in the management plan how the mean monthly LPUE of 2002 and 2007 is calculated and whether it is based on the data of the full fleet, fishing hours (FH) or hours at sea (HS) and if cooked or fresh weight of all or only of shrimps declared for human consumption were used. Hence, a first try from our side to re-calculate the mean LPUE for 2002 and 2007 from logbook data and landings declaration data failed; the exact values as written down in the management plan could not be reproduced.

Regarding the calculation of the monthly LPUE which is calculated at the end of each calendar month and then compared to the reference value, the management plan and the HCR state that monthly LPUE data for all vessels will be gathered from electronic logbook and auction data (auction data are equivalent to the landing declaration data). In 2016, the data from the electronic logbooks were not yet available to the steering committee, thus the committee did depend on the POs to submit the necessary data to calculate the monthly LPUE. Again, a first try from our side to re-calculate the monthly LPUE for 2016 from logbook data and landings declaration data failed; the exact values as used by the committee could not be reproduced.

We would therefore recommend to specify a detailed procedure how to calculate the monthly LPUE and the reference values from logbook and landings declaration data. The data collection process is visualized in Figure 25. The approach is described in five steps (see below) and tested with logbook and landing declaration data from the German fleet (Table 1). The Dutch and Danish data from logbooks should be processed accordingly.

1) The logbook entries of all vessels fishing for brown shrimp over 12 m are aggregated by trip number and month.
2) For the effort, hours at sea (HS) for all vessels are calculated as difference of leaving and return to port.
3) For landings, the weight of cooked shrimp which is declared for human consumption is taken from the landings declarations of all vessels and aggregated by trip number and month.
4) All landings and all effort data from all countries are summed up per month before taking the mean to take into account the difference in landings per country.
5) The monthly LPUE is calculated as kg landings per HS.

In case that logbook data might not be available in time to the steering committee, a similar approach could be applied to the (raw-) data submitted by the POs. The calculation of the monthly LPUE in five steps could be easily done by applying a routine written in a statistical analysis software (such as “R”) to a pre-defined EXCEL table where the data is entered by the POs.

As described above, neither the monthly LPUEs, nor the reference values as applied in 2016 by the management committee and the HCR could be reproduced from our side by using logbook data (not all results of all tested calculations are shown here). This may be due to different data used; logbook data were not available to the steering committee in 2016. Logbook data from Denmark were not available at the time of this analysis, therefore the analysis focuses on Dutch and German Data only.

Depending on the values which were calculated, different scenarios would have taken place in 2016 when logbook data would have been used for the management (Table 2). The results did show that for the monthly LPUE calculation the data of the full fleet should be used instead of those from a reference fleet. When reference values based on the recommendations from Temming *et al.* (2013) are used, the HCR would have been triggered far more often in 2016. For preventing confusion, abbreviations as specified in Table 1 are used.

For the German fleet, the LPUECur_D in column 1 is lower than the LPUELOG_D (column 2) except from April to June. April and June were the months which actually triggered the HCR in 2016.

For the Dutch fleet, the LPUECur_NL (column 3) is lower than the LPUELOG_NL (column 4) in January, February, June and July. In all other Month the LPUECur_NL is higher than LPUELOG_NL. As described in Table 1, LPUECur_NL is based in the data derived from a reference fleet, the reference fleet overestimated the LPUE in comparison to the full fleet in eight out of twelve months.

The LPUE for the full fleet as used by the management (LPUECur_all, column 5) is higher than the overall LPUE, which is partly based on logbook values, LPUELOG_all (column 6) from March to May, August, September and November and December. When the LPUEs in column 5 and 6 are compared to the reference values used in the management (RefHCR, column 7), LPUELOG_all would have triggered the effort restriction of the HCR already in March.

When the LPUEs in column 5 and 6 are compared to the reference derived from logbook data (RefLOG, column 8), the use of LPUECur_all (column 5) would have resulted in five month (January to May) with effort restriction, while LPUELOG_all (column 6) would have resulted in effort restriction of the HCR from March to May. When 75% of the mean LPUE of all years from 2002 to 2013 (RefTEM, column 9) would have been used, only July and August would have been open to fishing without effort restriction.

Table 1. Reference value and monthly LPUE provided by the steering committee (grey background) and calculated from logbook and landings declaration data (transparent background). RefHCR was taken from the management plan. Four values for the monthly LPUE were provided by the steering committee ($LPUE_{Cur}$_(D, NL, DK, all)). One reference value (Ref_{LOG}) was calculated from German logbook and landing declaration data as the mean of 2002 and 2007 of all vessels above 12m length based on the weight of cooked shrimp declared for human consumption and HS (hours at sea). Two monthly LPUE values ($LPUE_{LOG}$_D, $LPUE_{LOG}$_NL) were calculated for each month in 2016. The $LPUE_{LOG}$_D of the German fleet was based on data of all vessels above 12m length and kg cooked shrimp declared for human consumption per HS. The $LPUE_{LOG}$_NL of the Dutch fleet was based on data of all vessels and kg of all shrimp in the logbooks per HS as it was unclear whether the landings in the logbooks did refer to cooked/fresh weight and all shrimp or human consumption only. The data from $LPUE_{LOG}$_D and $LPUE_{LOG}$_NL were combined with $LPUE_{Cur}$_DK as Danish data were not available in disaggregated form to calculate a monthly reference value for the full fleet ($LPUE_{LOG}$_all).

An additional reference value (Ref_{TEM}) was calculated according to the recommendations from the evaluation of the Dutch HCR (Temming *et al.* 2013). Ref_{TEM} was calculated from German logbook and landing declaration data as 75% of the mean LPUE of all years from 2002 to 2013 of all vessels above 12m length based on the weight of cooked shrimp declared for human consumption and hours at sea.

Abbreviation	**Data source**	**Effort data**	**Landings data**	**Vessel filter**
Ref_{HCR}	Management plan	Unknown	Unknown	Unknown
$LPUE_{Cur}$_D	Steering committee / POs	HS	All shrimp including human consumption and undersized	Only MSC vessels
$LPUE_{Cur}$_NL	Steering committee / POs	HS	Unknown	Only reference fleet
$LPUE_{Cur}$_DK	Steering committee / POs	HS	Unknown	Unknown
$LPUE_{Cur}$_all	Steering committee / POs	HS	Unknown	Unknown
Ref_{LOG}	Logbook and landing declaration, mean of monthly LPUE for 2002 and 2007	HS	Only shrimp for human consumption, cooked	All vessels > 12m
$LPUE_{LOG}$_D	Logbook and landing declaration	HS	Only shrimp for human consumption, cooked	All vessels > 12m
$LPUE_{LOG}$_NL	Logbook	HS	Unknown	All vessels
$LPUE_{LOG}$_all	$LPUE_{LOG}$_D and $LPUE_{LOG}$_NL combined with $LPUE_{Cur}$_DK	HS	mixed	mixed
Ref_{TEM}	Logbook and landing declaration, mean of monthly LPUE of all years from 2002-2013	HS	Only shrimp for human consumption, cooked	All vessels > 12m

Table 2. Comparison of combinations of reference value and monthly LPUE for 2016 provided by the steering committee (grey background) and calculated from logbook and landings declaration data (transparent background).

Columns 1–4 show the LPUE values as calculated for each country separately. Column 5 shows the monthly LPUE for 2016 as used by the steering committee and derived from data submitted by the POs. Column 5 shows the monthly LPUE 2016 as calculated from Dutch and German logbook and Danish PO data. It has to be kept in mind that the values in column 5 and 6 are not the means of the LPUEs in column 1–4 plus the value for Denmark, but are weighted by the total landings and effort per country.

Column 7 shows the reference value (Ref 1) as used in the management plan. Column 8 shows the reference value calculated in the same manner (70 % of the mean of 2002 and 2007), but the calculation based on data from logbooks and landing declarations. Column 9 shows the reference value as recommended by Temming (2013).

Those fields marked bold in column 7–9 would have triggered the effort restriction by the HCR. The fields with a red frame in column 7–9 mark these months were the monthly LPUE from column 5 was below the respective reference value. The fields in yellow in column 7–9 mark these months were the monthly LPUE from column 6 was below the respective reference value.

	1	2	3	4	5	6	7	8	9
Month	$LPUE_{Cur}$_D [kg/HS]	$LPUE_{LOG}$_D [kg/HS]	$LPUE_{Cur}$_NL [kg/HS]	$LPUE_{LOG}$_NL [kg/HS]	$LPUE_{Cur}$_all [kg/HS]	$LPUE_{LOG}$_all [kg/HS]	Ref_{HCR}	Ref_{LOG}	Ref_{TEM}
1	17.07	18.43	19.52	19.69	16.44	18.77	16.36	**18.26**	**20.36**
2	13.76	14.82	14.90	15.71	13.90	15.02	12.39	**14.42**	**15.62**
3	12.17	12.26	16.02	14.63	14.21	13.78	**14.12**	**15.97**	**16.28**
4	11.58	11.04	14.84	11.85	13.52	12.06	**14.20**	**16.55**	**20.72**
5	10.33	10.22	15.07	10.46	12.58	10.96	**13.50**	**15.38**	**20.93**
6	14.97	14.71	19.40	21.19	17.38	18.11	12.17	13.05	**20.3**
7	18.30	18.41	30.74	32.43	23.50	25.52	16.98	15.77	21.57
8	19.49	19.97	51.28	46.02	34.41	33.34	22.27	19.69	25.89
9	16.01	17.19	42.25	41.54	31.53	30.47	26.20	24.75	**34.22**
10	18.24	19.06	51.85	49.71	34.23	36.72	26.52	24.50	**37.46**
11	16.22	16.54	37.33	34.44	27.27	25.76	20.75	21.52	**32.23**
12	11.78	13.43	24.36	22.91	19.51	19.13	16.78	18.20	**25.54**

A detailed analysis of the weekly effort in the weeks 20 to 23 in 2016 (with effort restriction to 72 hours at sea per week in week 22 and 23, see Figure 26) did reveal that fishing effort in parts of the German Bight was sharply reduced as result of application of the HCR in June 2016. In the German fleet, with onset of the effort restriction in week 22 the overall German effort was reduced by nearly 30% with most of the effort reduction taking place in two rectangles. The LPUE in this region did increase one week afterwards what could possibly be caused by a recovery of the shrimp stock. This effect should be further investigated. In the Dutch fishery, the mean weekly effort increased in week 23 to 72 HS, the same level as in week 20 before the effort restriction.

Data from German and Dutch logbooks were analyzed to determine local low and high abundances of brown shrimp in 2016. The mean LPUE per rectangle and month was calculated as proxy for brown shrimp abundance (see Table 3). Reference values were taken from the HCR (for the Dutch fleet) and calculated from logbook data (for the German fleet) to determine LPUEs of relatively low and high abundances.

Table 3. Data basis for LPUE and reference value calculation for the spatial analysis of local low and high abundances of Brown shrimp in 2016.

	Figure 26 (NL)	Figure 27 (G)
LPUE calculated per rectangle	$LPUE_{NL}$: Mean monthly LPUE [landings (kg) per HS] from logbook sheets	$LPUE_{D}$: Mean monthly LPUE [landings in fresh weight (kg) per FS] from logbook sheets
Reference values	Ref_{NL}: Taken from the Management plan; based on mean monthly LPUE of 2002 and 2007 (% levels see legend) as Dutch logbook data for 2002 and 2007 was not available	Ref_{D}: Calculated from logbook data; based on the mean monthly LPUE in fresh weight (kg) per FS of 2002 and 2007 (% levels see legend)

The LPUE in rectangles which were fished in the same month by Dutch and German vessels cannot be compared directly due to the different data used (see Table 3). Figures 27 and 28 show that $LPUE_{D}$ and $LPUE_{NL}$ in 2016 in March, April and May were below the 70% reference value (Ref_{NL} and Ref_{D}) in most rectangles. In March, April and May $LPUE_{LOG}$_all and $LPUE_{Cur}$_all (only April and May) were also below the Ref_{HCR} (Table 3).

The Dutch fleet is showing higher LPUE values for June to October than the German or the Danish fleet. These high values are solely generated in southern waters off the Dutch and German coast (Figure 27). From March to May, most fishing operations of the Dutch fleet in northern waters produce low $LPUE_{NL}$ which in fact led to the effort restrictions according to the HCR rules.

For the German fleet (Figure 28), the overall picture shows below-average LPUE most of the year and LPUE below the reference values in spring and from July on. The German $LPUE_{D}$ remained below the 70% reference value in most rectangles in the second part of the year, while the Dutch LPUE was above the 70% (and often above 100% of the Ref_{NL}) in most rectangles in the second half of 2016. Accordingly, the fishery could continue in the German bight without effort restrictions despite very low shrimp abundance, only because high Dutch LPUE values did outbalance low German $LPUE_{D}$ values.

The same effect can be seen on the rectangle scale in both graphs (Figure 27, Figure 28): while the LPUE of some rectangles is below the first reference value or even lower, the LPUE of other rectangles is above 100% of the relevant reference value. Drastic examples, such as single rectangles with $LPUE_D$ values far above the surrounding rectangles in February, June, August November December for the German data are likely caused by a few very successful fishing trips in these single rectangles compared to far more trips in the surrounding rectangles with far less success. In other cases, such as the above-average LPUE in three ICES rectangles off the coast of Schleswig-Holstein in February ($LPUE_{NL}$ above 110% Ref_{NL}), are likely resembling a true picture of the abundance of brown shrimp due to a large number of trips in those rectangles. It can thus be concluded that Brown shrimp abundance is not only highly variable on a large scale (such as Schleswig Holstein and Netherlands) but also on a smaller scale of on ICES rectangle. The calculation of one monthly LPUE for the full area (as intended in the current management plan) leads to disappearance of these variations.

It can be assumed that the HCR in the current design is likely not effective in preventing local low abundances from additional high fishing effort. It is highly recommended to investigate into a spatial component of the HCR which is triggered by local low abundances and is effective in reducing fishing mortality on specific areas. It is further recommended to investigate different approaches of weighting the LPUE to reduce possible over- and underestimation of the Brown shrimp abundance through a fishing stop of some vessels or concentration of the fishery on shrimp aggregation (and thus underrepresentation of areas of low abundance in the LPUE calculation).

Dynamics of brown shrimp and its fisheries

A mechanistic model of the dynamics of Brown shrimp and its fishery was built in 2015 at Wageningen Marine Research and presented in 2016 (Steenbergen *et al.*, 2015). The model describes the shrimp population and fleet dynamics in the eastern coastal zone of the North Sea from the south of the Netherlands up to the Danish west coast. The aim was to provide a scientifically sound ecological knowledge base for the exploration of management options for the North Sea brown shrimp fishery. The mechanistic approach resulted in a model that is based on the processes which lead to observed patterns, rather than on the patterns themselves. The strongly mechanistic basis of the model and the independently established parameterization, coupled with good correspondence of the dynamics exhibited by the model to that observed, make that the model can be reliably used to estimate the effects of various management scenarios.

Science Highlights

Brown shrimp specific management decision support tools can be used to evaluate strategies on how to sustainable and efficiently harvest the brown shrimp stock. WGCRAN has been advising the fishing industry in the design of the management strategy to achieve a sustainable use of the brown shrimp stocks in the North Sea within the framework of the MSC certification. This strategy is described in the brown shrimp management plan[1]. The work presented investigates necessary refinements of the brown shrimp management plan to avoid overfishing as implemented and executed by the fishery itself. The brown shrimp management plan represents the first case of a self-management of a large scale fishery in European waters.

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1 http://www.garnalenvisserij.com/wp-content/uploads/2016/06/20160609-Management-plan-v11-English-correct-ref-table.pdf

5.4 ToR d) Effects of new gears

In 2017, a research project was started by a cooperation Wageningen Marine Research (WMR) in The Netherlands, the Institute for agricultural and fisheries research (ILVO) in Belgium and Thünen-Institute of Baltic Sea Fisheries (Thünen) in Germany. The general question of the project is whether or not shrimp fishing using pulsetrawls result in higher amounts of undesired bycatches of undersized shrimp, fish and benthos as compared to the traditional shrimp beamtrawl fisheries, and if these possible differences are affected by time and location of the fisheries. After investigating the differences in selectivity of pulse and conventional gears, the project aims to contribute to further development and innovation of current shrimp pulsegears. The outcome of this project supports evaluation of sustainable management of shrimp fisheries in general and in marine conservation areas, e.g. Natura2000, in particular.

Cooperation with other WG

WGFTFB, WGELECTRA

Science Highlights

The shrimp industry has an important task to reduce their impact on the ecosystem. One of the tools to reduce this impact on for example the shrimp stock and the bycatch of other (fish) species is develop new/other innovative gears. The research that is designed around these innovations provide insight in how effective these new gears are in relation to the traditional methods. The working group raised the concern of long term effects on crangon stocks, and stresses the importance of proper management and long term monitoring when introducing new, and potential more efficient gear techniques. To avoid overlap with the above mentioned technical WG the group agreed that this should be the focus of discussion related to new gear development.

5.5 ToR e) Possible methods to assess and manage the brown shrimp fisheries

Evaluation of bycatch

In order to maintain the MSC certificate the following recommendation is given to the industry with regard to the registration of bycatch: *The design and collection of improved catch composition data across all three countries is encouraged, so that bycatch data can be compared and trends noted; ie harmonized Dutch and German (and Danish) sampling programmes and methods (MSC certificate report[2]).*

Catch composition data is available from observer programmes of the DCF regulation. However, the coverage is low and in Germany and the Netherlands the monitoring effort represents less than 1% of days-at-sea sampled. Observer programmes are cost consuming and thus a self-sampling program could be an alternative. However, depending on the method chosen, risks with self-sampling are that some of the fish species of the catches are under represented. If there is a representative (self) sampling program in place,

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[2] https://www.msc.org/docs/librariesprovider8/de/zertifizierung-nordseekrabben/20171103-nsbs-pcr-final.pdf

next important question is what does it say. Of many (non-commercial) species in the bycatch, the population size is not known. Therefore, the bycatch data of these species cannot be put in perspective.

Another important parameter to include in was the bycatch data into perspective is the discards survival of under-sized shrimp. A series of discard survival experiments have been conducted on board of two commercial vessels (Bönisch 2017). One aim was to test to what extent the earlier results of about 80% discard survival rates (Lancaster & Frid 2002) are applicable to the German fishery using mostly rotary sieves and larger vessels. The second aim was to observe the discard survivors longer than the 24 h applied in Lancaster & Frid (2002) and to also register if the survivors can successfully moult. Two cutters were chosen, a small one with a riddle sieve which was comparable to the one used in the earlier study and a larger vessel with a rotary sieve. Haul duration was varied between 5 min and 120 min with the 5 min hauls serving as baseline. Shrimp were sampled from the holding device and after passing the sieves and transported to an aquarium facility for further observation. One of the most striking results was a very high immediate mortality even in the 5 min hauls during the May campaign with mortality rates between 7 and 34% which increase subsequently to between 32 and 66%. One hypothesis to explain this unexpected result was an effect of intense fishing in the days prior to the experiment in the same region, which may have led to a large number of shrimps having undergone the discard procedure repeatedly. In the other months mortality rates within 24 h were below 10% as described by Lancaster & Frid (2002) but increased up to 29% for the 120 min hauls after 21 days of observation.

Boiling factor of *Crangon crangon*

Landings data (logbook entries) of brown shrimp *C. crangon* are used for broad purposes (e.g. to evaluate the fishing pressure on the species; Tulp *et al.* 2016, FAO 2000). The logbook uses the live weight of the animals caught. However, brown shrimp are landed after being boiled on board directly after catch. In order to convert the boiled weight to the live weight equivalent, the national authorities use defined factors (FAO 2000). Despite the purpose to set a common data base, the conversion factors used are different between nations ranging from 1.00 to 1.25 (i.e. Belgium: 1.25; Germany, Netherlands, Portugal = 1.18; France: 1.10, Denmark: 1.00, FAO 2000).

A new investigation on the effect of boiling on the body parameters of C. crangon basing on individual measurements (n=319) was analysed together with earlier studies performed at the German Thünen Institute (Riemann 1995, unpublished; n=441). Based on these measurements, a linear regression analysis (r^2=0.99) resulted in a conversion factor of 1.07 (Figure 29). Accordingly, the mean individual loss in body weight was less than 10%.

The results encouraged a debate on the accuracy/comparability of the data reported and summarized by the different nations, as well as the need to adjust the conversion factors used by the different national authorities.

Science Highlights

Data on catch rates of bycatch in the brown shrimp fisheries should be put into perspective in terms of the total population of the species caught and also discards survivability should be taken into account.

According to the findings presented, landings data of most nations are overestimated when back-calculated fresh-weight is used. This highlights the need to critically evaluate (and adjust) the different nations' procedure when reporting the landings data of *C. crangon* fisheries (i.e. the use of the conversion factor from boiled to fresh weight). This is important for accurate estimation of the stock status and modelling purposes like e.g. the evaluation of the fishing pressure on the *C. crangon* stock.

References

FAO 2000. *Conversion factors - landed weight to live weight*. Food and agriculture organization of the United Nations. Fisheries Circular No. 847, revision 1, p. 135.

Lancaster, J., & Frid, C. L. J. (2002). The fate of discarded juvenile brown shrimps (*Crangon crangon*) in the Solway Firth UK fishery. Fisheries Research, 58(1), 95-107.

Tulp, I., C. Chen, H. Haslob, K. Schulte, V. Siegel, J. Steenbergen, A. Temming, and M. Hufnagl. 2016. Annual brown shrimp (*Crangon crangon*) biomass production in Northwestern Europe contrasted to annual landings. ICES Journal of Marine Science 73:2539–2551.

5.6 ToR f) Infection levels with bacilliform viruses and/or the occurrence of other diseases

This ToR is very specific and has little to do with the overall aim of the WG. The PhD working on this topic was not present at the meeting. The WG decided during the meeting in 2017 that this ToR would not be discussed any further.

5.7 ToR g) Potential on using brown shrimp as a species for use in aquaculture system

At the University of Hamburg a series of new growth experiments was conducted to investigate to what extent reproducible high growth rates can be induced with optimal diets and ad libitum feeding. Once successful, such feeding tests could be used to detect growth limitation in the field by transferring shrimp to the lab and contrasting the initial increments with subsequent increments realized under optimal diets. Currently tested diets include Acartia tonsa copepods reared on a rhodomonas diet, which have proven successful in preliminary trials (Hufnagl & Temming 2011)

The group jointly decided in 2017 that the other part of ToR, focus aquaculture was not not relevant for this group and would no further be discussed.

Reference

Hufnagl M, Temming A (2011) Growth in the brown shrimp *Crangon crangon*. II. Meta-analysis and modelling. Mar Ecol Prog Ser 435:155-172.

5.8 ToR h) Optimize and harmonize German and Dutch surveys

The Dutch DFS and the German DYFS are used to estimate the total mortality and a swept area biomass index (Tulp *et al.* 2016) of *Crangon crangon* along the coast of the south-western North Sea area, including the inshore areas of the Wadden Sea. The total mortality estimate is based on length-based methods and includes all survey data (Dutch and German data). The swept biomass index uses also data from both surveys, but for the area 405 and 406 only Dutch data were used so far because of the better station coverage of the area before 2013. The German data of *Crangon crangon* abundance and distribution were presented to the group for the reporting period (Figure 30, Figure 31).

The gears in use of the Dutch DFS and the German DYFS are not totally standardized. The DFS uses a 3m beam trawl with one tickler chain in the inshore part of the survey and a 6m beam trawl with one tickler chain in the more offshore areas. The German DYFS uses a 3m beam trawl without tickler chain in all survey areas. The 3m beam used in the more offshore areas (deployed by the FRV Clupea) is heavier than the one used in the inshore areas. The possible differences in the catchability of *Crangon crangon* are not known. To estimate the survey comparability of DYFS and DFS, *Crangon crangon* abundance indices of two overlapping sampling areas (405 and 406) were compared over a period from 1997 to 2016. The preliminary results highlighted the still existing need for performing parallel hauls in the future (ICES 2018). In the past some attempts were already made to perform parallel hauls in order to compare the catchability of the different gears in use (ICES 2016a; Schulte pers. communication; ICES 2016b). However, in all cases the number of hauls was not sufficient to obtain any conclusive results. The last parallel hauls which could be conducted with RV Isis and Clupea were done in 2014 opportunistically during the Dutch and German surveys, but only a few parallel hauls were possible. In the actual reporting period (2016–2018) it was not possible to conduct further parallel hauls, because there was no time besides the regular survey grids to perform extra hauls. Therefore, there was no progress in the harmonization and optimization of the Dutch and German surveys. WGCRAN recommends initiating a joint gear comparison project between the WMR and the Thünen Institute.

References

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ICES. 2016b. Report of the Working Group on Beam Trawl Surveys (WGBEAM), 14-17 April 2015, Leuven, Belgium. ICES CM 2015/SSGIEOM:20. 148 pp.

ICES. 2018. Report of the Working Group on Beam Trawl Surveys (WGBEAM). Working Group on Beam Trawl Surveys (WGBEAM) 4-7 April 2017. Galway, Ireland. 121 pp.

Tulp, I., C. Chen, *et al.* 2016. Annual brown shrimp (*Crangon crangon*) biomass production in Northwestern Europe contrasted to annual landings. ICES Journal of Marine Science. doi:10.1093/icesjms/fsw141.

Changes/ Edits/ Additions to ToR

For the next three years reporting period of WGCRAN it was decided to change the ToR as such that WGCRAN will only focus on the analyses of the survey data and time-series.

The task of optimization and harmonization is already a ToR of the ICES WGBEAM and is covered there (ICES 2016b).

Science Highlights

Optimize and harmonize German and Dutch surveys will help to improve comparability, to analyze spatio-temporal trends of stock indicators (biomass, distribution, mortality, etc.) and to ground-truth VMS derived LPUE estimates.

5.9 ToR i) Exchange of information

The Danish EMFF Crangon project

The Danish EMFF Crangon project "Hesterejer i Nordsøen" has applied for a one year prolongation of the project. Provided that this project is accepted, the project will focus on three major topics:

- Analyze bycatch data (the Danish DCF data)
- Initiate biophysical modelling of larval drift
- Modelling population dynamics (adapting a size-based model) and geographical distribution of the Crangon populations in general
- Examine alternative management strategies (such as closed areas and time periods)

A series of new ideas for developing an EMFF project proposal for next year were discussed. The overall aim is to go deeper into the seasonal distribution of Crangon in different regions. This work includes modelling of the dynamics of Crangon distribution and compilation of recruitment indices. It is not decided if the required data can be found in existing surveys (stomach analysis, IBTS, DCF) or additional surveys is needed e.g. a biomarker experiments to verify the model. It is the intention to try to extend an international survey into the unfished Danish area to provide a baseline for comparing CPUE, catch sizes and fishery induces injuries and mortality on both Crangon and fish.

We expect the data from the bycatch time-series to be a backbone in the models and analysis, and that the outcome and experience from the Danish bycatch surveys will contribute to the network activities within the Dutch (EMFF) initiative together with gear technology. Gear technology will by the gear technology group at DTUA Aqua through the Danish EMFF project FastTrack and other projects.

General recommendations

Harmonize data so it is comparable between countries e.g., weight of the catch (boiled or raw), effort (hours), boiling factor, size fractions (how many times are they sieved).

Share anonymized VMS and landing data to get a better spatial understanding of the fishery/stock.

Alternative management strategies are recommended.

Research needs in future

- Is there meta-population structure? If yes, should the fishery be managed with respect to these?
- The vertical distribution pattern of the Crangon larvae including considerations about the behaviour of the larvae in relation to the diel and tidal cycles (important for the larval dispersion model).
- Species interactions of relevant species in the Wadden Sea for a better understanding of natural mortality of Crangon.
- Recruitment indices from new/existing relevant surveys?

Effects of food availability on moulting cycle and growth of C. crangon

Under laboratory conditions, starvation experiments were performed at the IMF of the University of Hamburg to clarify how withdrawal of food affects the moulting interval, condition and growth of common brown shrimp (*Crangon crangon*).

In recent years, various studies investigated the influence of different factors on the growth of brown shrimp. The authors identified size, temperature, sex, cohort, food availability and -type as ones influencing growth. As most of these studies focused on growth increment, the moult interval was so far only assumed to be a function of temperature. Therefore, the recent study focused on possible effects of food availability influencing the moult cycle.

Moulting intervals varied significantly with treatment and prolonged with increasing starvation period (Figure 32). It was shown that at 17°C water temperature every day of starvation delayed the next moult event by another day (Figure 33). Pre-moult condition as well as growth increments after each respective starvation period decreased significantly with the duration of food withdrawal. Accordingly, the combination of decreasing increments and prolonged moult intervals resulted in a significantly reduced growth rate within animals deprived of food compared to animals fed throughout the experimental period (Figure 34). A decrease in post moult body length was already known for other decapod crustacean species, but so far there were only a few indications and studies that documented negative growth of brown shrimp. Within this study we were able to detect a correlation between food withdrawal and negative growth increments.

Since several life-history-traits of brown shrimp are highly related to periodic moults, e.g. fertilization and egg deposition, the results of this work could contribute to a better understanding of starvation periods influencing growth as well as reproduction of the stock.

Science Highlights

Contrary to the assumption, that moult interval is only a function of temperature, it was shown that in periods of bad nutritional condition, these intervals extend, and all moult related life history traits are influenced. This observation, as well as the fact that some individuals show a decreased post moult size when exposed to bad nutritional condition, will contribute to an improved understanding of growth in general and can thus be considered as factors implied in future growth models.

CRANIMPACT Project

CRANIMPACT is an EMFF-Project, in which the Thünen Institut in Bremerhaven and the Institute for marine Ecosystems and Fishery Science (University of Hamburg, IMF) and the DTU Auqa (Tecnical University of Denmark) will investigate the effects of shrimp fisheries on habitats and benthic communities in coastal waters of the northern German states of Schleswig-Holstein, Hamburg and Niedersachen (Germany). The four-year project is divided in four working packages; 1) Analysis of benthic communities along gradients of fishing intensity; 2) Regeneration of sediment and community structure after experimental fishing; 3) Physical impact of beam trawl shrimp fishery on the seabed, and 4) Synthesis of experimental and observational data to estimate the impact of shrimp fishing on the Wadden Sea ecosystem. Analysis of VMS data, to identify areas with different fishing intensities as well as Before-After-Control-Impact (BACI) experiments are planned. Based on a habitat oriented approach, three different habitats for the BACI experiments are chosen. Beyond that, the physical effect of beam trawl fisheries on different habitats will be quantified. As a reference area, seabed structures and benthic communities in a part of the Danish Wadden Sea, where shrimp fishing has been prohibited for decades, is being investigated for the first time.

Science Highlights

The results will make an important contribution to the discussion on the compatibility of nature conservation efforts and fishing activity.

6 Cooperation

- **Cooperation with other WG**
    - WGELECTRA on pulse-gear developments, ongoing projects and research results.
    - WGSFD to share results/methods of VMS data analysis

7 Summary of Working Group self-evaluation and conclusions

The WGCRAN self-evaluation is given in Annex 4.

Annex 1: List of participants

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Annex 2: Recommendations

Recommendation	Adressed to
1.Spatial analysis of effort would improve future management decisions. If not available from nations directly, aggreagted log-book and/or VMS data of the ICES data base (OSPAR-HELCOM data call) could proabably be used for a fleet-wide analyses	Germany, Denmark, Netherlands, SCICOM EGs and ICES Data Centre.

Annex 3: WGCRAN terms of reference 2019–2021

The **Working Group on *Crangon* fisheries and life history** (WGCRAN), chaired by Claudia Günther*, Germany, will work on ToRs and generate deliverables as listed in the Table below.

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2019	8–10 October	IJmuiden, Netherlands		Claudia Günther was elected as new chair from 2019 onwards
Year 2020				
Year 2021				

Supporting information

ToR	Description	Background	Science Plan codes	Duration	Expected Deliverables
A	Data collection of the status of the Crangon stock.	To report and evaluate population status indicators like recent landings and effort trends in the brown shrimp fisheries or length based mortality estimates from Dutch and German scientific surveys. Generate a standardized lpue time-series and provide a detailed description of the process of collecting the dataseries effort, landings & LPUE for WGCRAN.	1.1; 2.1	year 1,2,3	A time-series analysis of the standardized stock indicators shall be delivered by all WGCRAN members within each annual report.
B	Compilation of Logbook information & VMS analysis	To combine VMS, landings and effort data to gain a population distribution indicator and to monitor regional distribution and regional shifts in fishing effort.	2.1; 2.4; 3.5; 5.4	year 1,2,3	Results will be summarized in a peer-reviewed paper.
C	To develop a suite of decision-support tools	To develop and evaluate brown shrimp-specific management decision-support tools to evaluate strategies on how to sustainably and efficiently harvest the brown shrimp stock.	2.1; 2.2; 5.1; 5.4 6.1	year 1,2,3	The results will be presented in technical reports and shall be summarized in a peer-reviewed paper.
D	To evaluate the	To evaluate the effects of new	2.1; 2.2; 5.4	year	An overview of

	effects of the efficiency of new gears on shrimp catches	gears (e.g. pulsetrawl, combined pulse-trawl and standard gears, large or new mesh types, pumpsystem, letterbox etc.) and their implications on the Crangon stock, the bycatch, the catch efficiency and the possible lpue based management strategies.		1,2,3	the considerations shall be summarized in the WGCRAN reports.
E	To synthesise the status of research of bottom impact of Brown shrimp fishing practices	To review the status and results of research of bottom impact and consider the implications for management.	2.4; 3.2	year 1,2,3	This work will be compiled and the results will be summarized in a peer-reviewed paper.
F	To review the status of research on bycatch	To review the status and results of research on bycatch timeseries and consider the implications for management. Evaluate methods and procedures used on board for collecting data on bycatch. Gather, compile and evaluate information on the onboard and ashore sieving fractions and processes and new national bycatch/discards data from e.g. DCF	3.1; 3.2	year 1,2,3	To standardize the available and agreed sampling procedures and compile results in the WGCRAN report.
G	To examine the life cycle dynamics of brown shrimps	To gain a better understanding of the life cycle dynamics and life history of brown shrimp in order to optimize models of population dynamics that are used for management purposes.	1.7; 5.2; 6.1	year 1,2,3	Results shall be summarized in a peer-reviewed paper.
H	To analyze German, Belgian and Dutch survey data	The analysis of spatio-temporal trends of survey based stock indicators (biomass, distribution, mortality, etc.) will be conducted. Additionally the ground-truth of VMS derived lpue estimates will be used as complementary information. The inclusion of Belgian survey data will help to complement this analysis.	3.1; 3.2	year 1,2,3	The results overview will be presented in each annual report.
I	To facilitate information	Information on national legislation, laws (e.g	7.1	year 1	An overview of relevant

	exchange	concerning Natura 2000) and developments (MSC process) concerning the brown shrimp fisheries in the whole North Sea will be synthesised.			legislations will be included in the report.
J	To provide supporting information on ongoing research	To present and review ongoing brown shrimp research in the ICES area, which can help to support and consider management implications.	6.1	year 1,2,3	The summaries of updates will be included in the annual report(s)

Summary of the Work Plan

Year 1	Stock status indicators (ToR a) shall be udated and harmonized between countries. German and Dutch survey data will be analysed and reported, Belgian data will be included in the analyses (ToR h) Information on national legislation, laws (e.g concerning Natura 2000) and developments (MSC process) concerning the brown shrimp fisheries in the whole North Sea will be summarized (ToR i). Data used for the compilaiton of manuscripts in support of ToR b, c, e, g will be made available. New information generated from ToRs d, f, j will be reported
Year 2	Stock status indicators (ToR a) willbe udated and harmonized between countries. German, Belgian and Dutch survey data will be analysed and reported (ToR h). Data for manuscripts related to ToR b, c, e, g will be made available. New information from ToR d, f, j will be reported.
Year 3	Stock status indicators (ToR a) will be updated and harmonized between countries. German, Belgian and Dutch survey data will be analysed and reported (ToR h). Data for Manuscripts related to ToR b, c, e, g will be made available. New information from ToR d, f, j will be presented and reported

Supporting information

Priority	Crangon fisheries are economically important with landings value ranking this species among the top three species caught from the North Sea. The priority of WGCRAN is to understand the interactions between the brown shrimp population (structure and abundance) and human behaviour (mainly fishing effort), the environment, and the ecosystem. One important aspect is and will be the monitoring, investigation and development of population status indices. WGCRAN is the only expert group to evaluate the Brown Shrimp Fisheries Management Plan which was developed by the industry in the course of the MSC certification.
Resource requirements	The research programmes that provide the main input to this group are already underway, and resources are already committed. The additional resource required to undertake additional activities in the framework of this group is negligible.
Participants	The Group is normally attended by some 10 members and guests.
Secretariat facilities	None.

Financial	No financial implications.
Linkages to ACOM and groups under ACOM	WGCRAN aims at a permanent linkage with ACOM after year 2 when sound and proven stock indicators and tools to evaluate management strategies have been developed(ToR a, b, c).
Linkages to other committees or groups	There is a linkage to WGBEAM as similar surveys are used. WGELECTRA as the use of the pulse gear by a larger fraction of the fisherman might have implications on the stock, WGINOSE by providing data for the integrated assessment. WGSAM as the SMS key runs will be used to estimate natural mortality of brown shrimp. Members of WGCRAN are also members in these groups.
Linkages to other organizations	CWSS = Common Wadden Sea Secretariat; TMAP = Trilateral Monitoring and Assessment Programme; RCM –NSEA

Annex 4: WGCRAN self-evaluation 2016-2018

1) Working Group name: Working Group on Crangon Fisheries and Life History (WGCRAN)

2) Year of appointment: 2016

3) Current Chair: Josien Steenbergen, Netherlands

4) Venues, dates and number of participants per meeting.

Oostende, Belgium, 23-25/05/2016, 10 participants

Hamburg, Germany, 7-9/11/2017, 12 participants

ICES HQ, Copenhagen, Denmark, 9-11/10/2018, 10 participants

WG Evaluation

5) If applicable, please indicate the research priorities (and sub priorities) of the Science Plan to which the WG make a significant contribution.

Goal 1 "Assess the physical, chemical and biological state of regional seas and investigate the predominant climatic, hydrological and biological features and processes that characterise regional ecosystems" and Goal 6 "Investigate linear and non-linear ecological responses to change, the impacts of these changes on ecosystem structure and function and their role in causing recruitment and stock variability, depletion and recovery."

WGCRAN has continued to identify and discuss the key mechanisms of how brown shrimp fisherman, predators and top predators interact. The North Sea underwent changes in the past and in the Wadden Sea the number of potential shrimp predators (cod, whiting) decreased. The released predation pressure increased the shrimps available for the fisherman. Parallel to the decline in shrimp predators the number of top predators (seals and whales) increased which keeps the cod and whiting abundance in the coastal areas of the southern North Sea low. Thus the whiting and cod dominated system with low shrimp catches changed to a top predator dominated system with high landings.

Goal 2 "Understand the relationship between human activities and marine ecosystems, estimate pressures and impacts, and develop science-based, sustainable pathways" as well as **goal 3** "Evaluate and advise on options for the sustainable use and protection of marine ecosystems."

Brown shrimp specific management decision support tools can be used to evaluate strategies on how to sustainable and efficiently harvest the brown shrimp stock. A strong focus of the group has been the development and evaluation of a management plan for a sustainable shrimp fishery. In 2013 – 2015 the work of the group and the WKCCM workshop finally led to a first advice including a roadmap on how to proceed to obtain a management plan to prevent from overfishing. The advice was used by the industry in developing a trilateral brown shrimp management plan[3] for the countries Germany, Denmark and the Netherlands. The management plan formed the basis for the shrimp industry of the three countries to become MSC certified. During this reporting period the WG has investigated the necessary refinements of the brown shrimp management plan to avoid overfishing as implemented and executed by the fishery itself. Bycatch data have been collected and anlyzed to identify the impact of the brown shrimp fisheries on other ecosystem components. In Germany a project has started in 2018 that will investigate the effects of shrimp fisheries on habitats and benthic communities in coastal waters of the northern German states of Schleswig-Holstein, Hamburg and Niedersachen (Germany).

Goal 28. Promote new technologies and opportunities for observation and monitoring and assess their capabilities in the ICES context

At one of the member institutes (ILVO, Belgium) a smart method to accurately measure the lengths of shrimp using a camera was developed and demonstrated (Smart Shrimp). The method is now also being used in the Netherlands.

Goal 29. Promote the development and testing of new fishing gear technology and methods for selective reduction of by-catch and discards and for mitigation of other environmental impacts of fishing

The shrimp industry has an important task to reduce their impact on the ecosystem. One of the tools to reduce this impact on for example the shrimp stock and the bycatch of other (fish) species is develop new/other innovative gears. The research that is designed around these innovations provide insight in how effective these new gears are in relation to the traditional methods. An important new gear technology that was also followed by this group is the use of pulse trawl to catch shrimp. The working group raised the concern of long term effects on crangon stocks, and stresses the importance of proper management and long term monitoring when introducing new, and potential more efficcient gear techniques.

6) In bullet form, list the main outcomes and achievements of the WG since their last evaluation. Outcomes including publications, advisory products, modelling outputs, methodological developments, etc. *

- Status stock Indicators were updated yearly
- Standardized LPUE time-series of higher accuracy for the Netherlands with horse power days calculated based on hours at sea generated.
- A smarter way of measuring shrimp lengths with the at ILVO developed SMART Shrimp is show cased to the group and now also applied in the Netherlands.
- ***Paper:*** Ingrid Tulp, Chen Chun, Holger Haslob, Katharina Schulte, Volker Siegel, Josien Steenbergen, Axel Temming & Marc Hufnagl (2016). Annual brown shrimp *Crangon crangon* biomass production in NW Europe contrasted to annual landings. ICES journal doi:10.1093/icesjms/fsw141.

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3 http://www.garnalenvisserij.com/wp-content/uploads/2016/06/20160609-Management-plan-v11-English-correct-ref-table.pdf

- ***Dissertation*:** The monitoring of the spatiotemporal distribution and movement of brown shrimp (*Crangon crangon* L.) using commercial and scientific research data
- ***Paper***: Schulte, K. F., Dänhardt, A., Temming, A., Hufnagl, M., Wosniok, W. 2018. Not easy to catch: multiple covariates influence catch rates of brown shrimp (*Crangon crangon* L.), potentially affecting inferences drawn from catch and landings data. ICES Journal of Marine Science 75(4): 1318-1328.
- ***Project Report***: Steenbergen, J., Kooten, T. van, Wolfshaar, K. van de, Trapman B., Reijden, K., van der., 2015. Management options for brown shrimp (*Crangon crangon*) fisheries in the North Sea. Imares report C181/15 (https://edepot.wur.nl/366175).
- ***Report*:** Georg Respondek, Margarethe Nowicki, Claudia Günther, Axel Temming. Scientific guidance and consulting for the brown shrimp management plan during the MSC-certification process – Part II. Final Report. Hamburg, Institute of Marine Ecosystem and Fishery Science (IMF), June 2018.
- ***Paper***: Steenbergen, J., Trapman, B.K., Steins, N.A., Poos, J.J., 2017. The commons tragedy in the North Sea brown shrimp fishery: how horizontal institutional interactions inhibit a self-governance structure, ICES Journal of Marine Science, Volume 74, Issue 7, Pages 2004–2011, https://doi.org/10.1093/icesjms/fsx053.

7) Has the WG contributed to Advisory needs? If so, please list when, to whom, and what was the essence of the advice.

Yes, it was a continuous process during the 3 year reporting period (2016-2018). The WG contributed to advisory needs of the fishing industry for their MSC certification. The WG evaluated the HCR and discussed scenario calculations concerning effects of mesh size and fishing effort on growth overfishing.

8) Please list any specific outreach activities of the WG outside the ICES network (unless listed in question 6). For example, EC projects directly emanating from the WG discussions, representation of the WG in meetings of outside organizations, contributions to other agencies' activities.

WGCRAN has been advising the fishing industry in the design of the management strategy to achieve a sustainable use of the brown shrimp stocks in the North Sea within the framework of the MSC certification. This strategy is described in the brown shrimp management plan[4]. The work presented investigates necessary refinements of the brown shrimp management plan to avoid overfishing as implemented and executed by the fish-

[4] http://www.garnalenvisserij.com/wp-content/uploads/2016/06/20160609-Management-plan-v11-English-correct-ref-table.pdf

ery itself. The brown shrimp management plan represents the first case of a self-management of a large scale fishery in European waters.

9) Please indicate what difficulties, if any, have been encountered in achieving the workplan.

- With regards to ToR b the member who was mainly involved in the analyses of VMS data did no longer join the WG. Also there was a lack of expertise in this field amongst other members from other countries with regards to this topic. That is why we were not able to make the progress we wished to make with this ToR
- After 1 year we had to conclude that the more aquaculture ToR's (f and g) where outside the scope of the working group. The only person working on these topics did no longer attend the meetings.

Future plans

10) Does the group think that a continuation of the WG beyond its current term is required?

The working group was positive about the continuation of the WG beyond its current term for the following reasons:

- Crangon fishery is a specific fishery on short lived species. It therefore needs a specific approach, different from other fisheries;
- Crangon fishery is an unregulated fishery that takes place in nature designated areas, it therefore needs monitoring;
- Ongoing self-management needs scientific advice;
- There is still a need for data integration and harmonization of national statistics;
- There is no other forum where results of above points can be discussed.

11) If you are not requesting an extension, does the group consider that a new WG is required to further develop the science previously addressed by the existing WG.

N.a.

11) What additional expertise would improve the ability of the new (or in case of renewal, existing) WG to fulfil its ToR?

We will need for at least the first meeting to be held in 2019 VMS and logbook experts from the different participating countries to participate.

12) Which conclusions/or knowledge acquired of the WG do you think should be used in the Advisory process, if not already used? (please be specific)

At the moment there is no request for advice for Crangon fisheries, however the group does provide recommendations and feedback to fisheries industry in the framework of their MSC certification. Crangon fishery takes place in nature conservation areas and nursery areas. It is a fishery with a small mesh size and effort is unregulated. The working group therefore advised the industry on:

- How to reduce bycatch by for example altering gears;
- Growth overfishing: Effort reduction or mesh size increase;
- Recruitment overfishing: Potential of HCR.

Annex 5: Figures

Total landings time-series and percentages landed per country

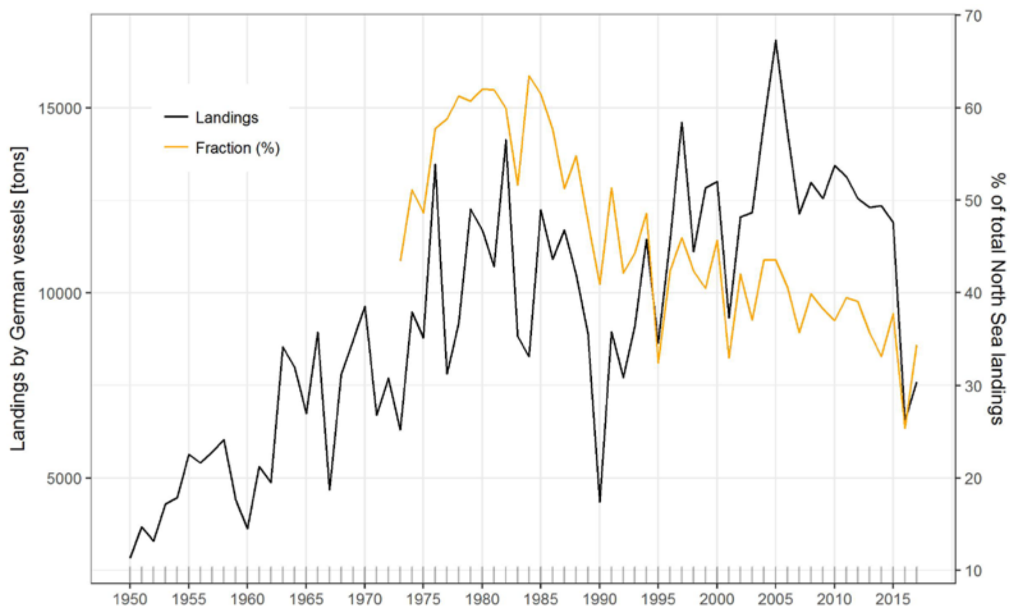


Figure 1. Consumption brown shrimp landed [tons] by German vessels over the period 1950 to 2017 (primary y-axis) in European harbours. Yellow line and second y-axis: Percentage of German landings in relation to total (whole North Sea, all nations).

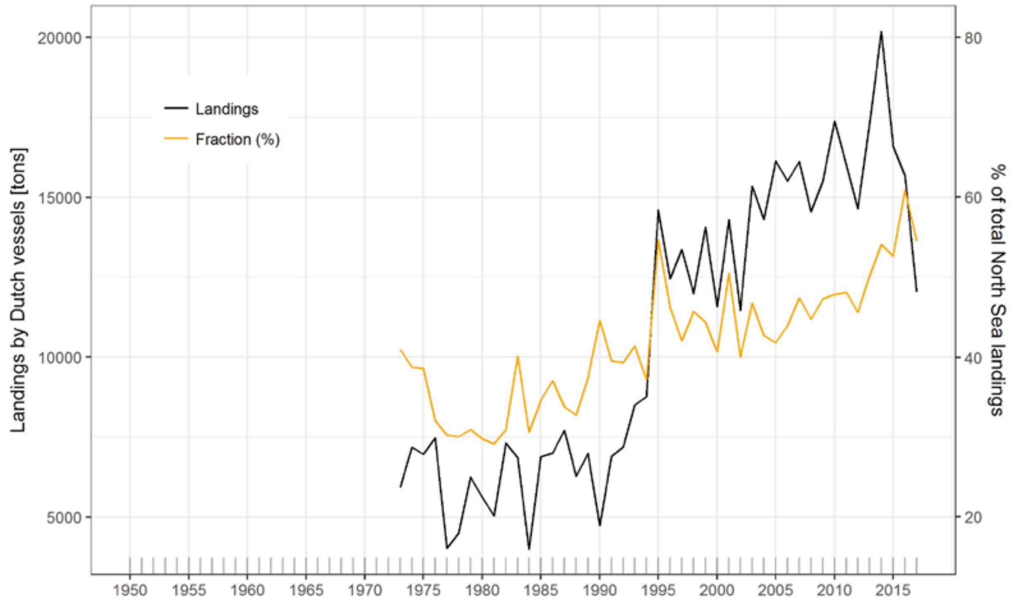


Figure 2. Consumption brown shrimp landed [tons] by Dutch vessels over the period 1973 to 2017 (primary y-axis) in European harbours (Data source before 1995; from Producer organisations (inclusion of foreign landings unclear), 1995 onwards; VIRIS log book data including landings in foreign harbours). Yellow line and second y-axis: Percentage of Dutch landings in relation to total (whole North Sea, all nations).

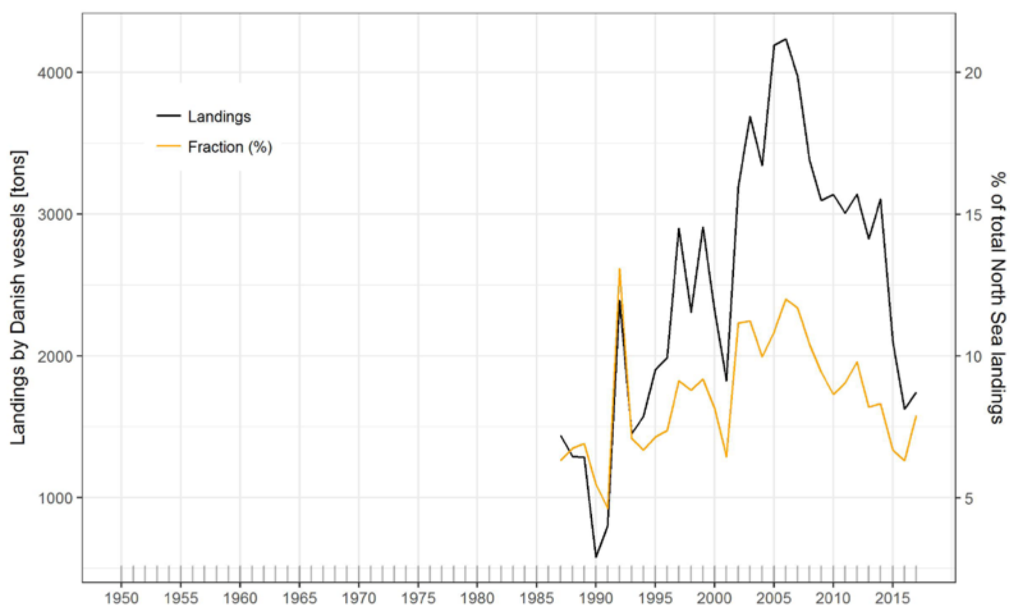


Figure 3. Consumption brown shrimp landed by Danish vessels over the period 1987 to 2017 (primary y-axis) in European harbours. Yellow line and second y-axis: Percentage of Danish landings in relation to total (whole North Sea, all nations).

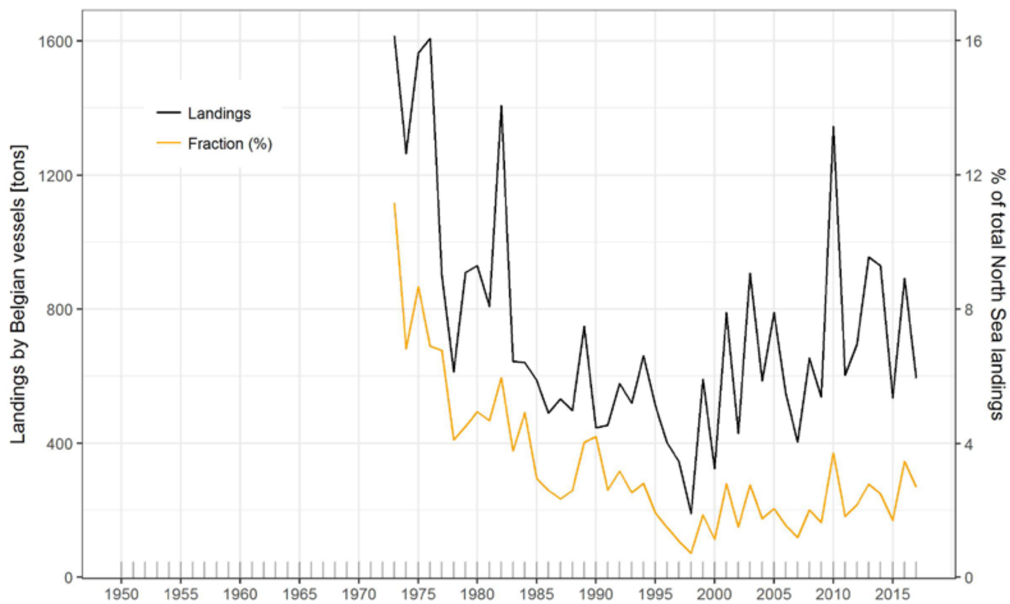


Figure 4. Consumption brown shrimp landed by Belgian vessels over the period 1973 to 2017 (primary y-axis) in European harbours. Yellow line and second y-axis: Percentage of Belgian landings in relation to total (whole North Sea, all nations).

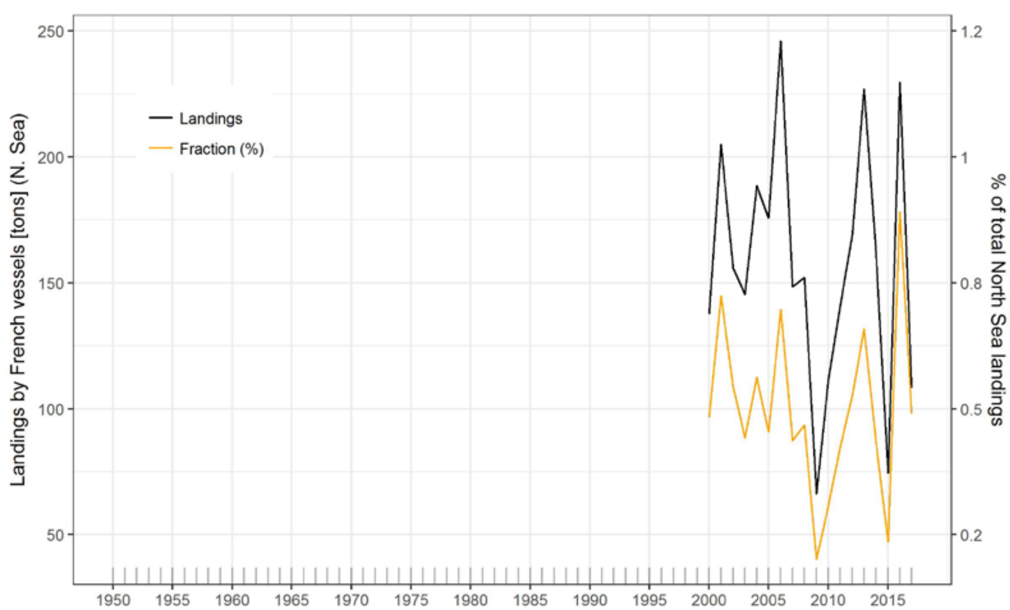


Figure 5. Consumption brown shrimp landed by French vessels over the period 2000 to 2017 (primary y-axis) in European harbours (North Sea, ICES area IV and VIId only). Yellow line and second y-axis: Percentage of French landings in relation to total (whole North Sea, all nations).

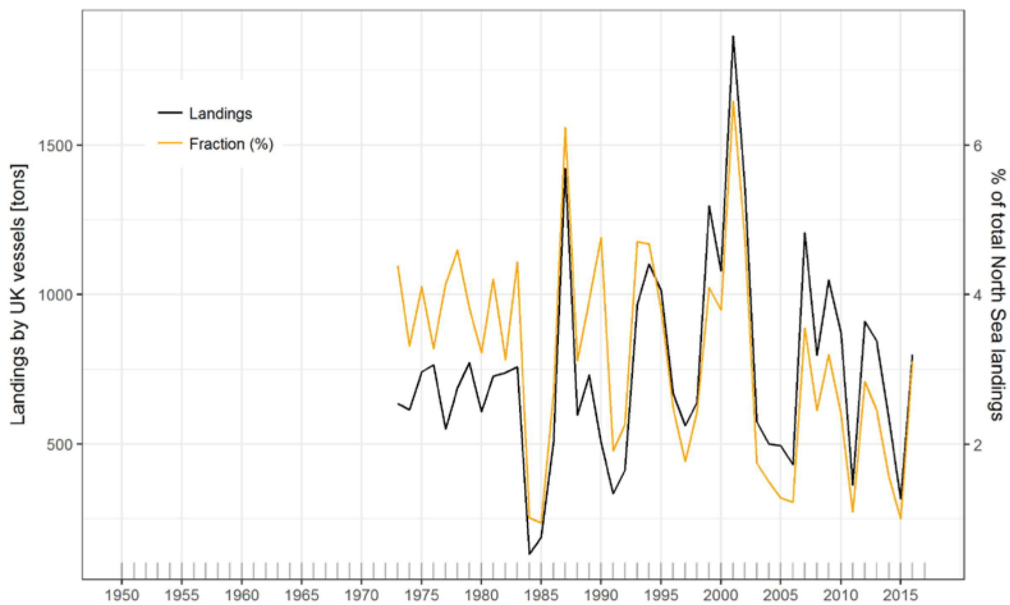


Figure 6. Consumption brown shrimp landed by UK vessels over the period 1973 to 2017 (primary y-axis) in European harbours. Yellow line and second y-axis: Percentage of UK landings in relation to total landings (whole North Sea, all nations).

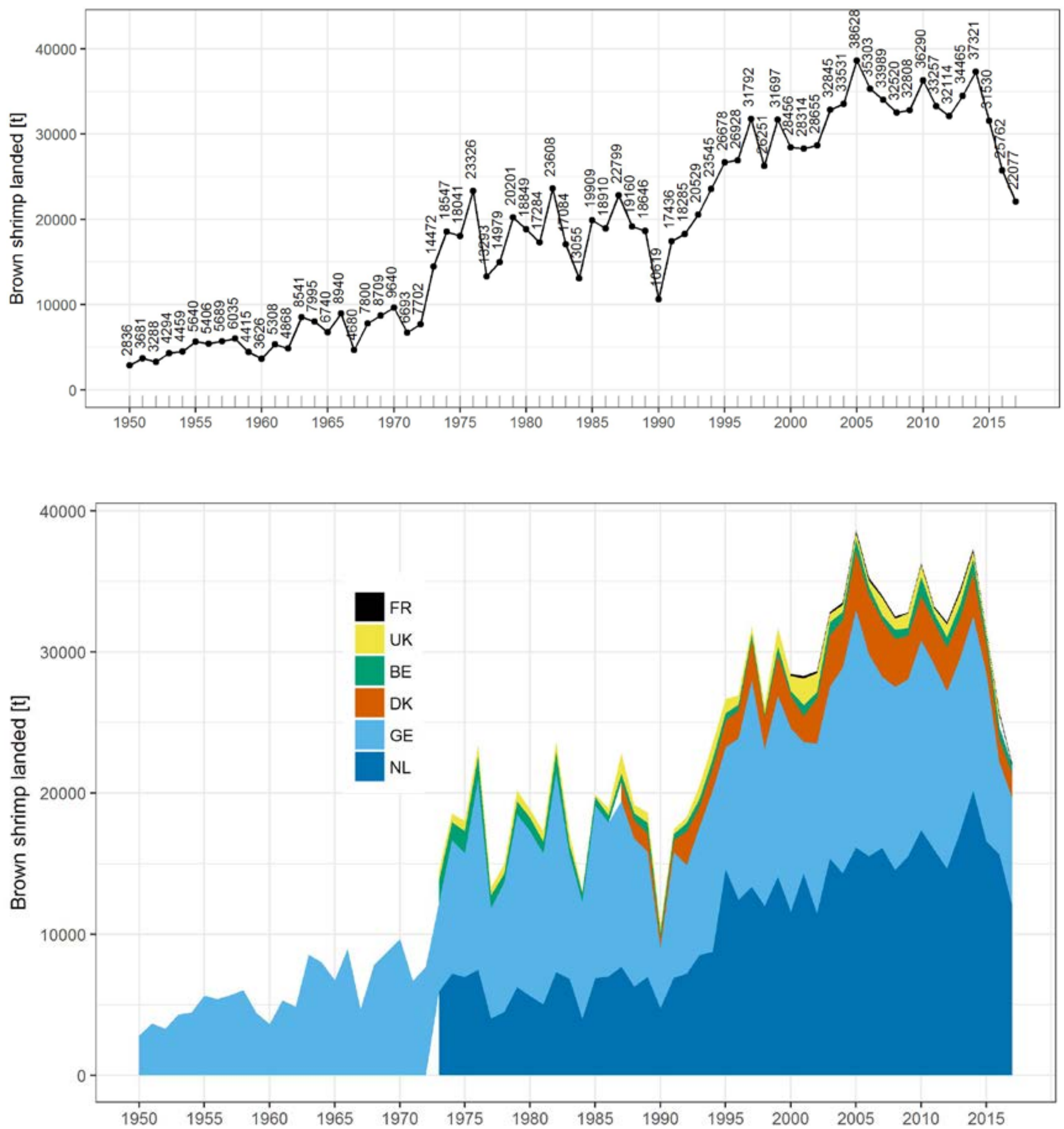


Figure 7. Upper panel: Statistics of total landings of consumption brown shrimp (*Crangon crangon*) from the North Sea [tons] 1950 to 2017 (yearly figures in the graph). Lower panel: Total landings of brown shrimp from the North Sea [tons] by country. (Data for UK 2017 is lacking.)

Seasonal (monthly) statistics by country

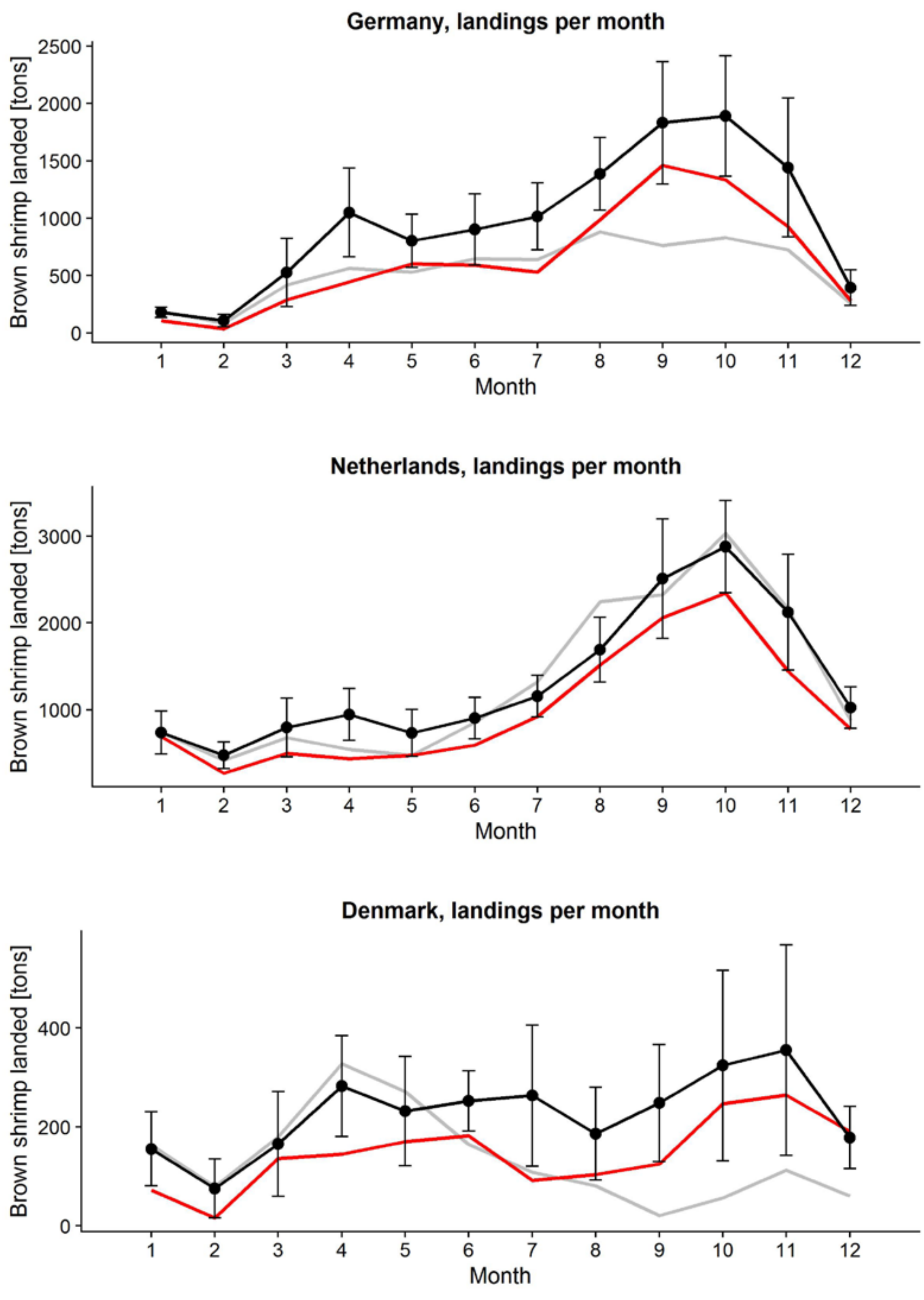


Figure 8a. Consumption brown shrimp landed per month and country (Germany, Netherlands and Denmark). Black line: 10 year average (2008–2017) and standard deviation (whiskers), grey line: total landings per month for the year 2016, red line: total landings per month for the year 2017.

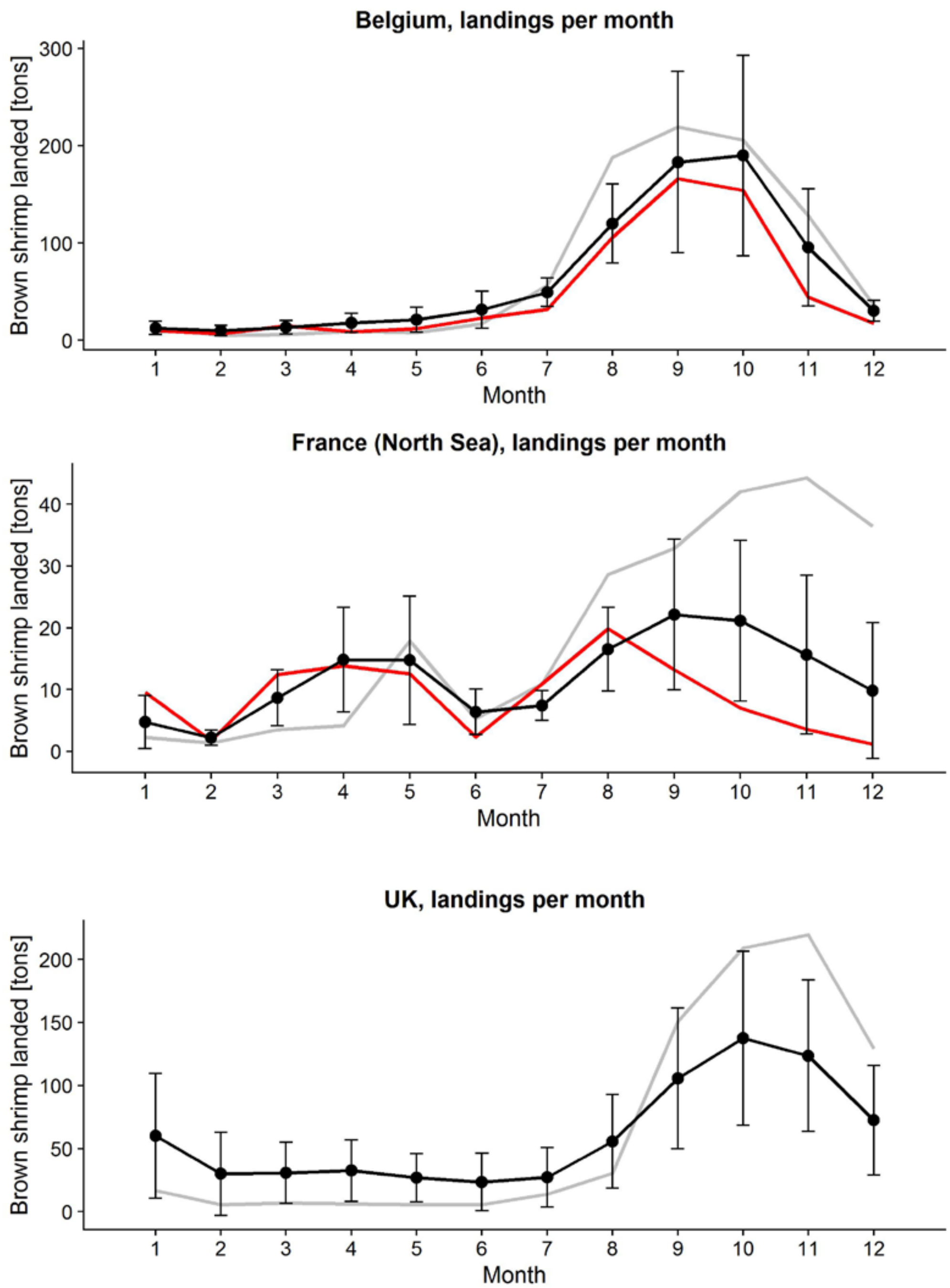


Figure 8b. Consumption brown shrimp landed per month and country (Belgium, France, UK). Black line: 10 year average (2008–2017) and standard deviation (whiskers), grey line: total landings per month for the year 2016, red line: total landings per month for the year 2017 (Data for UK 2017 is lacking, mean is for 2008–2016).

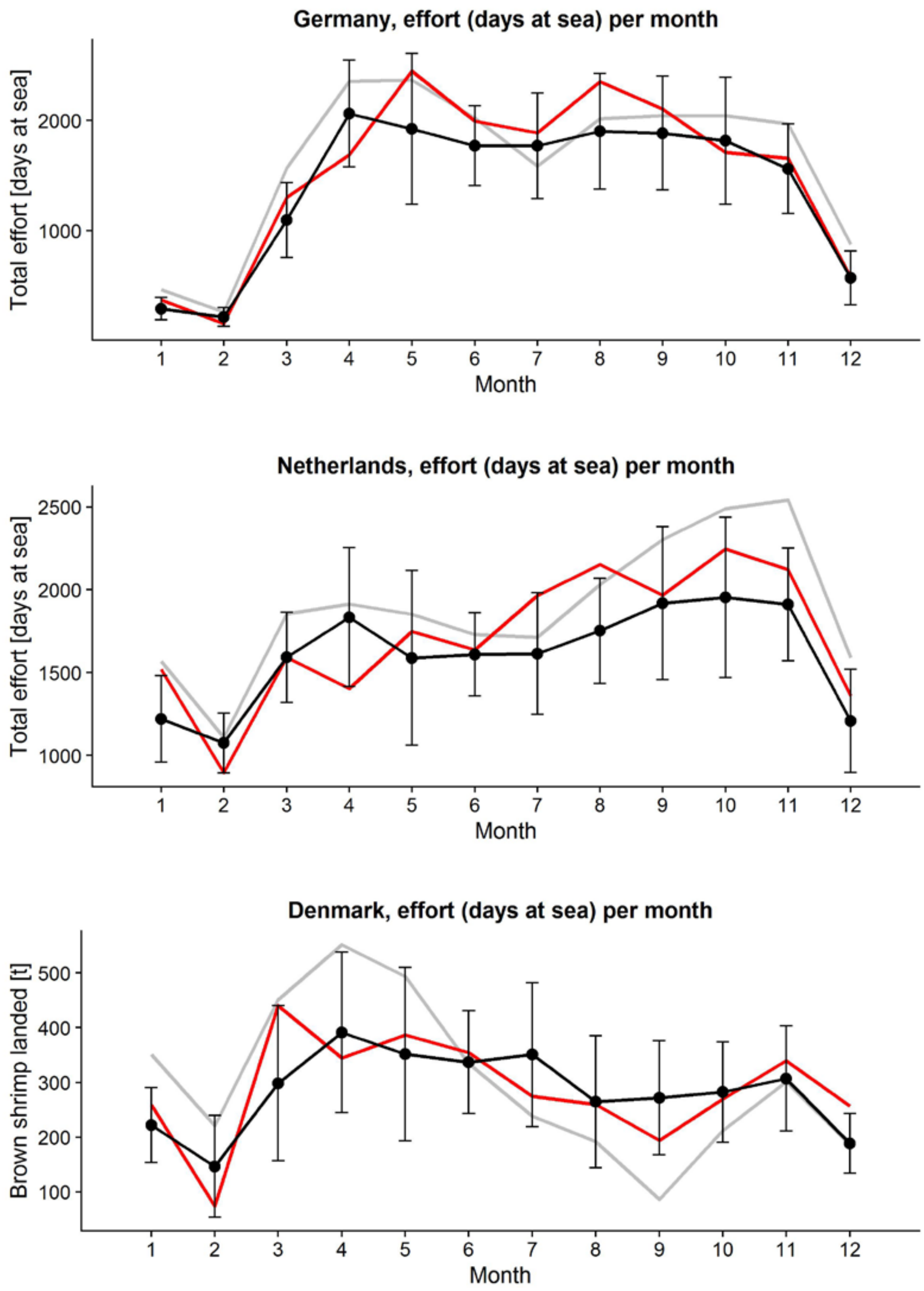


Figure 9a. Monthly effort in days at sea (from leaving to returning to harbour) of shrimp trawlers per country (Germany, Netherlands and Denmark). Black line: 10 year average (2008–2017) and standard deviation (whiskers), grey line: total landings per month for the year 2016, red line: total landings per month for the year 2017.

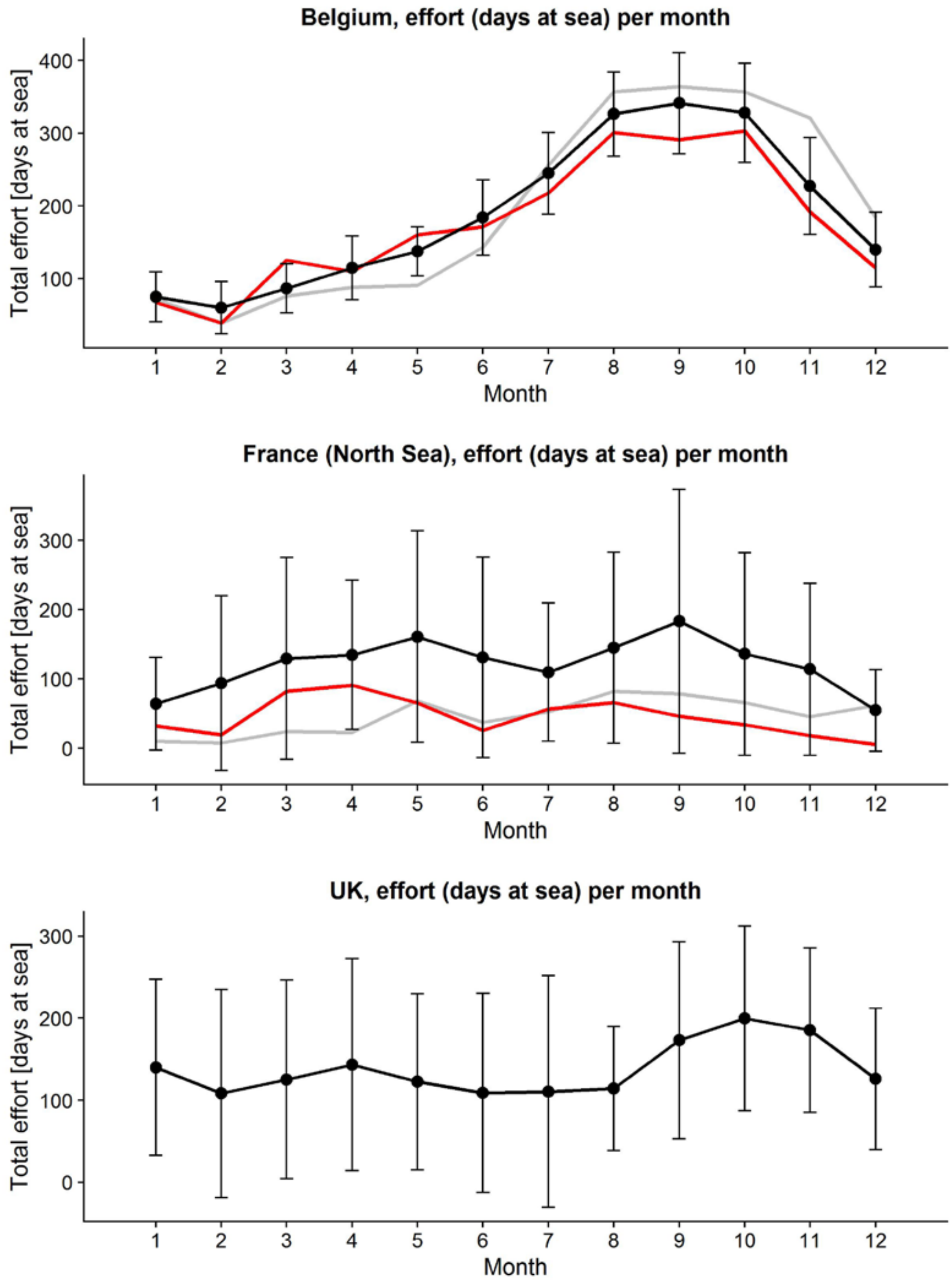


Figure 9b. Monthly effort in days at sea (from leaving to returning to harbour) of shrimp trawlers per country (Belgium, France, and UK). Black line: average (2008–2017 for Belgium and France, 2008–2015 for UK) and standard deviation (whiskers). Grey line: total landings per month for the year 2016, red line: total landings per month for the year 2017 (Data for UK 2016 and 2017 is lacking).

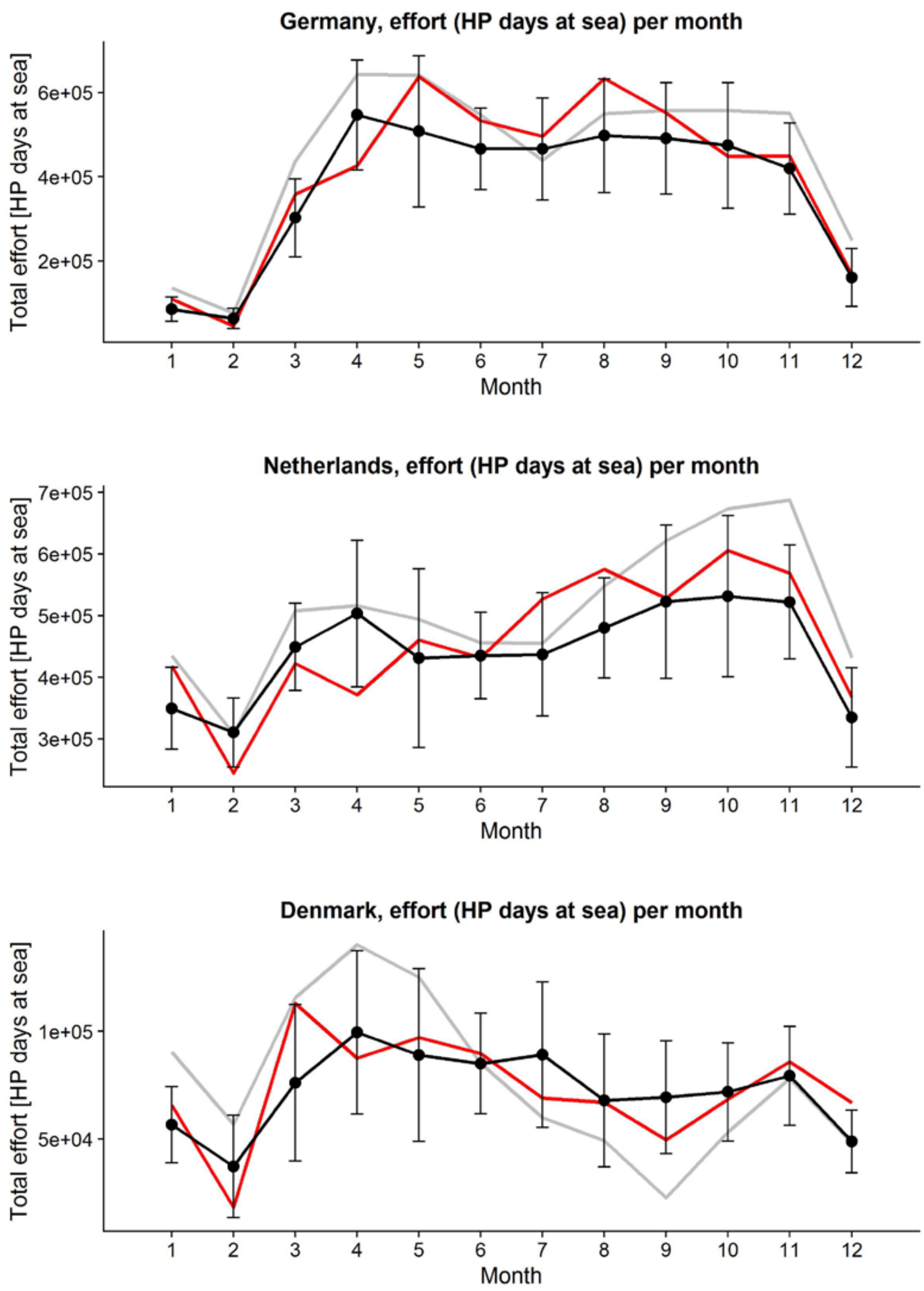


Figure 10a. Monthly effort in horse power days at sea (from leaving to returning to harbour) of shrimp trawlers per country (Germany, Netherlands and Denmark). Black line: 10 year average (2008–2017) and standard deviation (whiskers), grey line: total effort per month for the year 2016, red line: total effort per month for the year 2017.

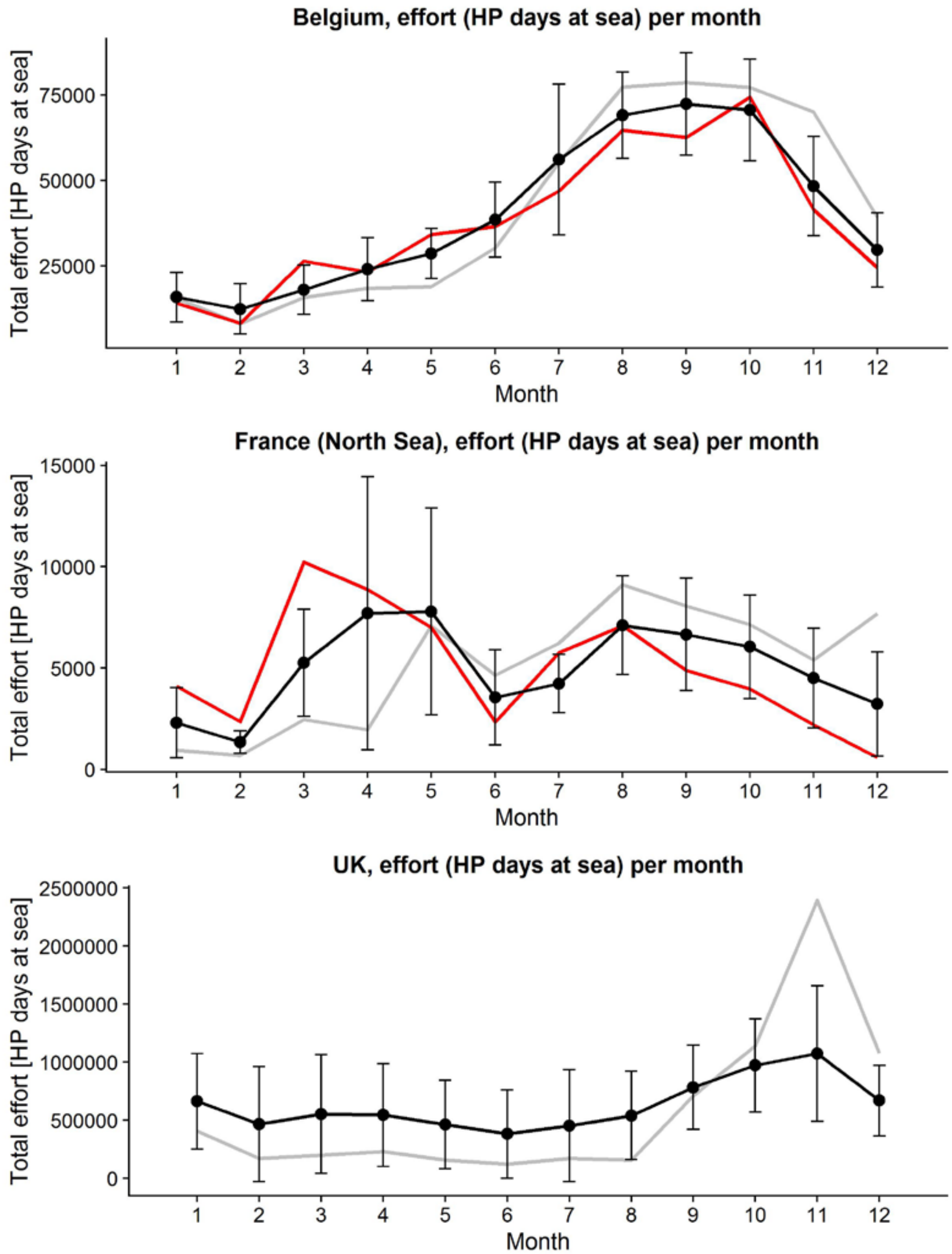


Figure 10b. Monthly effort in horse power days at sea (from leaving to returning to harbour) of shrimp trawlers per country (Belgium, France, UK). Black line: average (2008–2017 for Belgium and France, 2008–2016 for UK) and standard deviation (whiskers). Grey line: total landings per month for the year 2016, red line: total landings per month for the year 2017 (Data for UK 2017 is lacking).

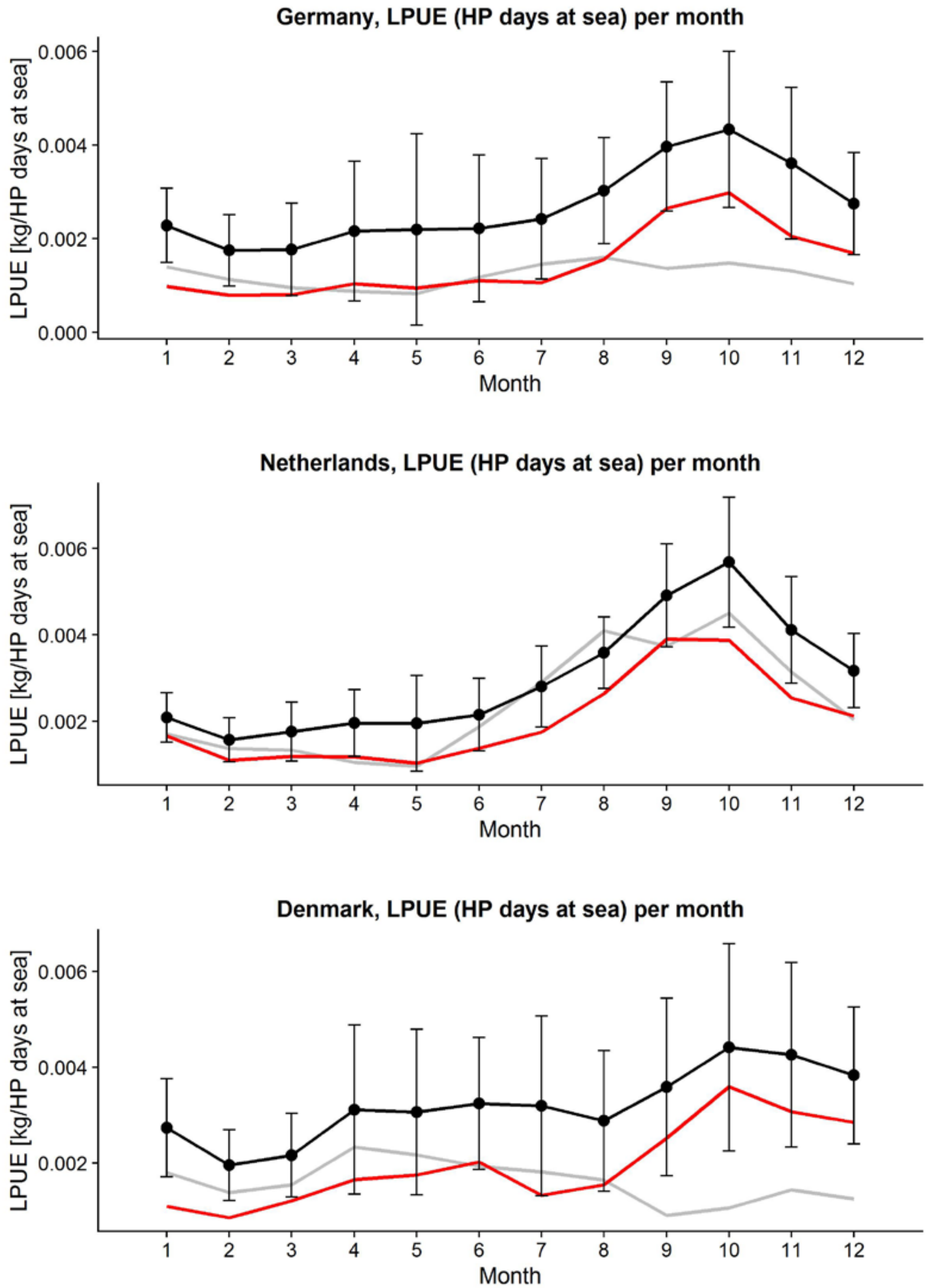


Figure 11a. Monthly landings of brown shrimp per unit effort (LPUE) in kg per horsepower days at sea per country (Germany, Netherlands and Denmark). Black line and whiskers indicate the 10 year average (2008–2017) and standard deviation (whiskers) for each nation. Grey line indicates the effort for 2016 and the red line the effort for 2017.

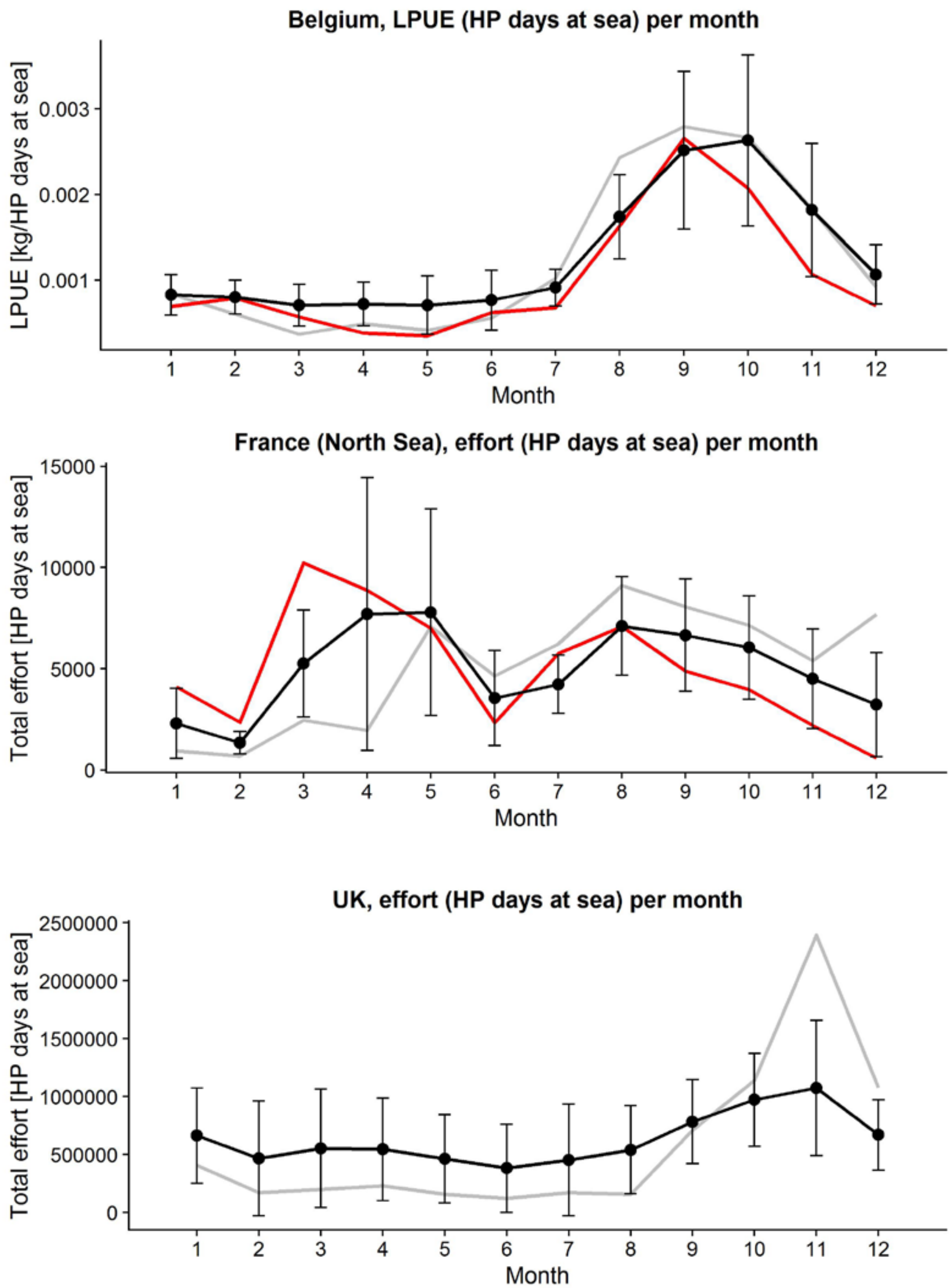
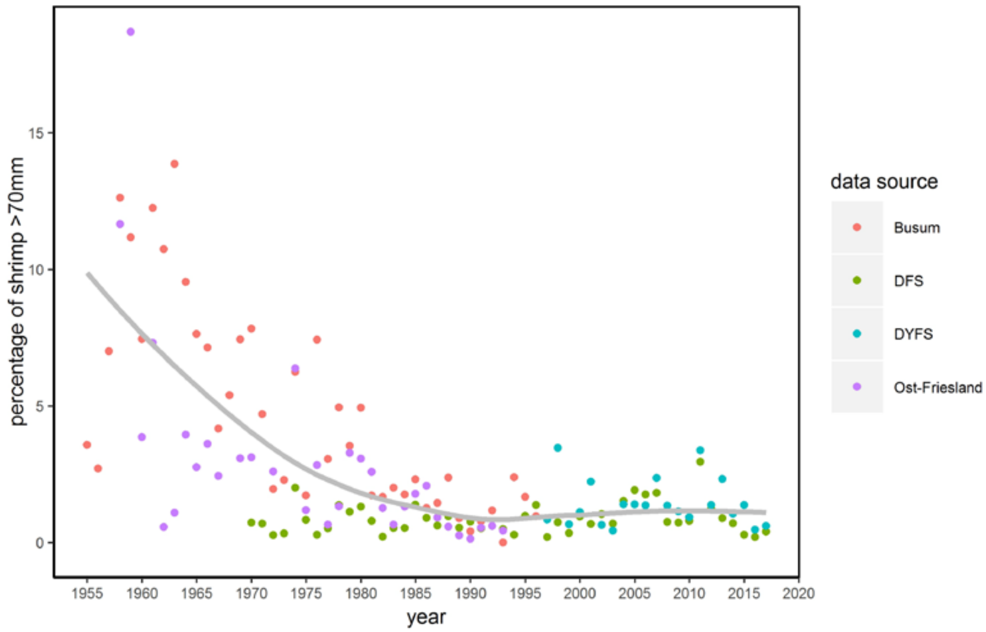


Figure 11b. Monthly landings of brown shrimp per unit effort (LPUE) in kg per horsepower days at sea per country (Belgium, France, UK). Black line and whiskers indicate the 10 year average (2008–2017) and standard deviation for Belgium and UK. For France, black line and whiskers indicate average and standard deviation of available years 2011–2017. Grey line indicates the effort for 2016 and the red line the effort for 2017 (Data for UK 2017 is lacking).



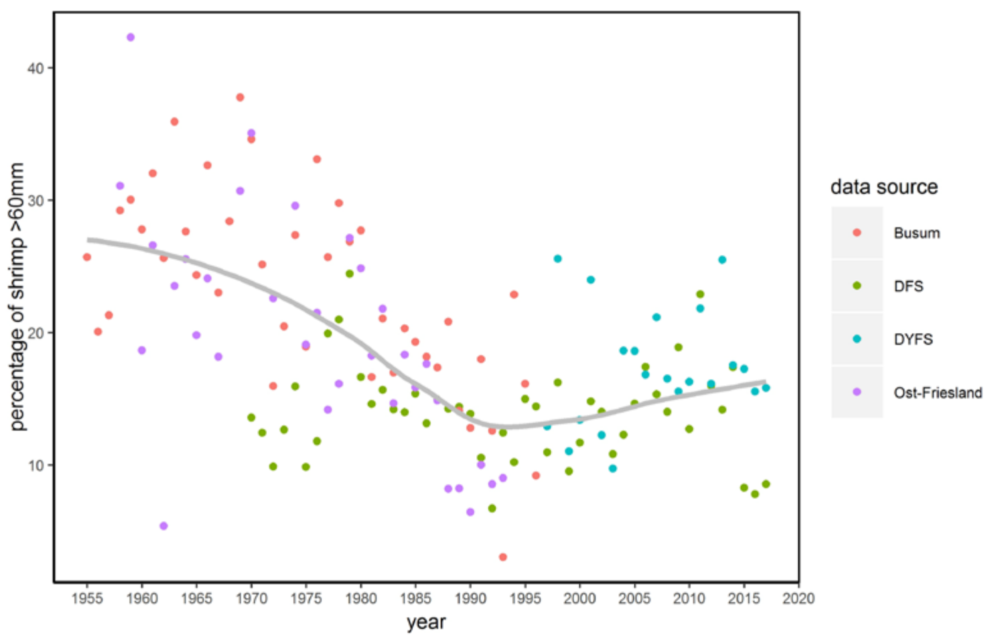


Figure 12. Time-series of proportion of large brown shrimp (>60 mm and >70 mm) in four different survey programs. The line is a Loess smoother. DFS and DYFS are fishery-independent surveys, Busum and Ostfriesland are German bycatch series. The fraction is expressed as the fraction of all shrimp >45 mm.

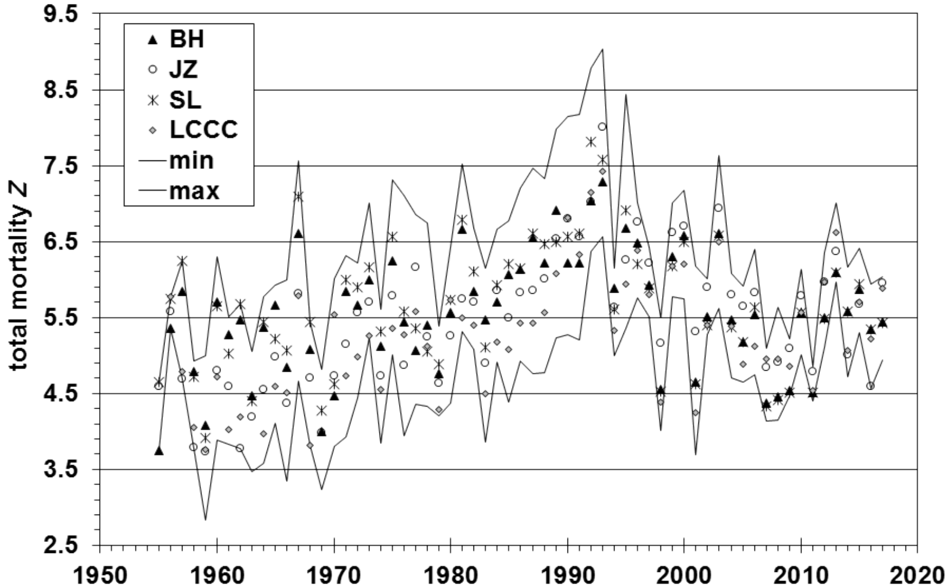


Figure 13. Total annual exponential mortality rate Z [a-1] estimated using length-based methods. Four different methods were used (represented by the different symbols): Beverton & Holt (BH), Jones and van Zalinge (JZ), Ssentongo & Larkin and Length Converted Catch Curve (LCCC). The methods and as well as the validation of the methods are presented in Hufnagl *et al.* (2010).

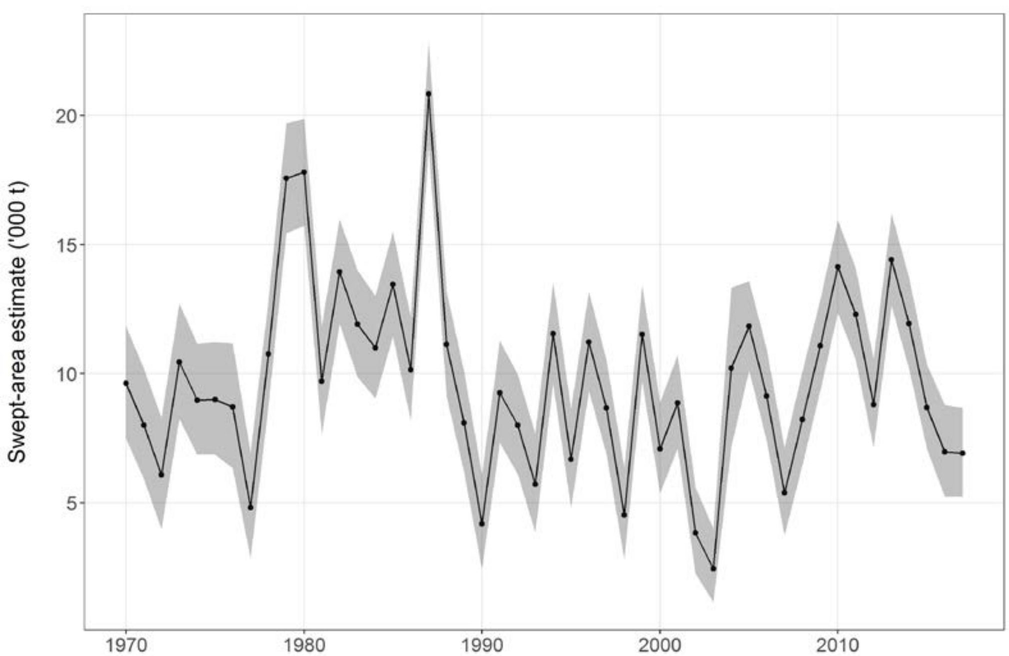


Figure 14. Time-series 1970–2017 and 95% confidence limits (grey area) of the swept area estimate as calculated according to Tulp *et al.* (2016).

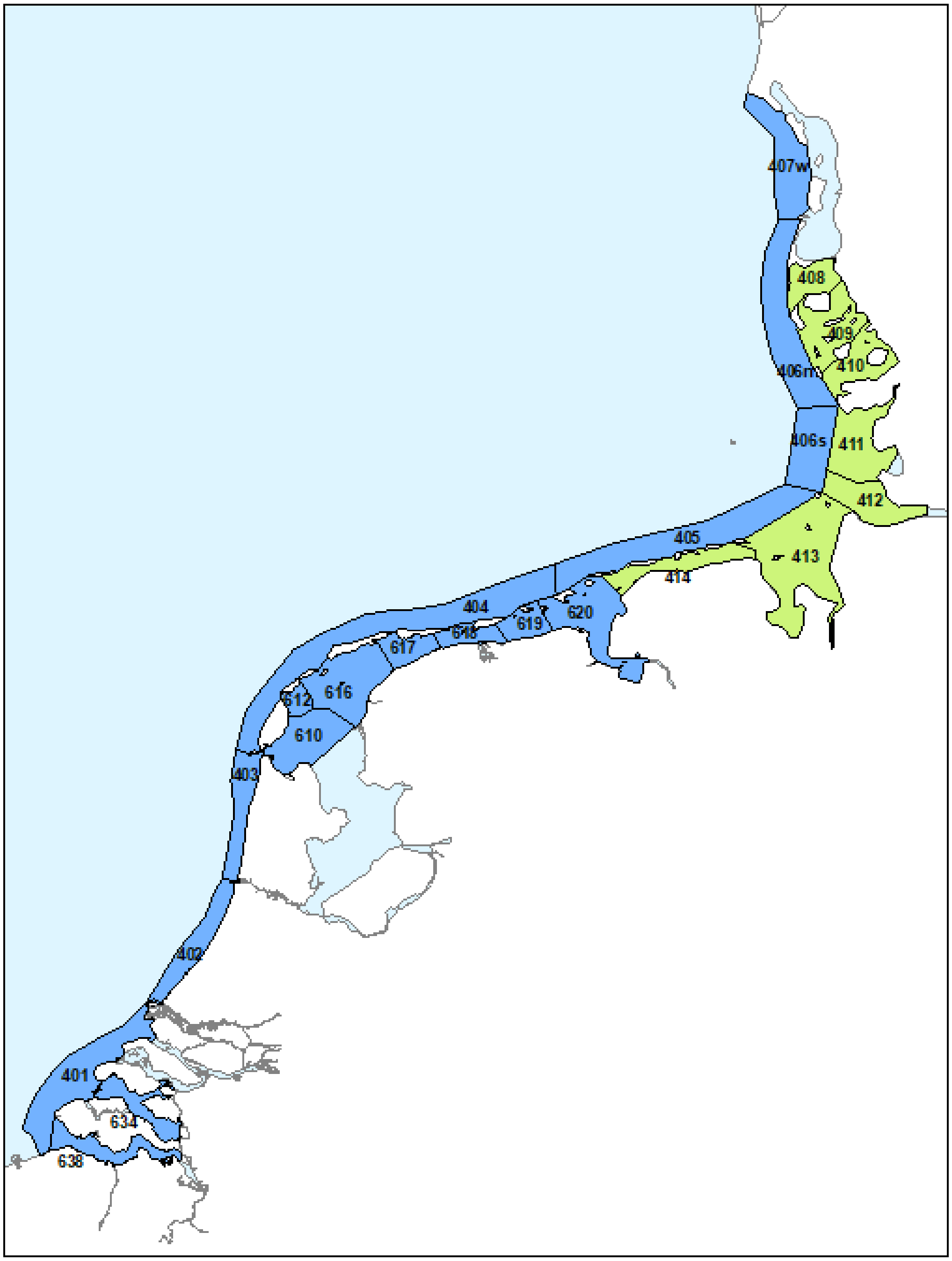


Figure 15. Map with all ICES areas used in this section. The blue areas are covered by the Dutch DFS, the green area by the German DYFS. Areas 405 and 406 are covered by both surveys.

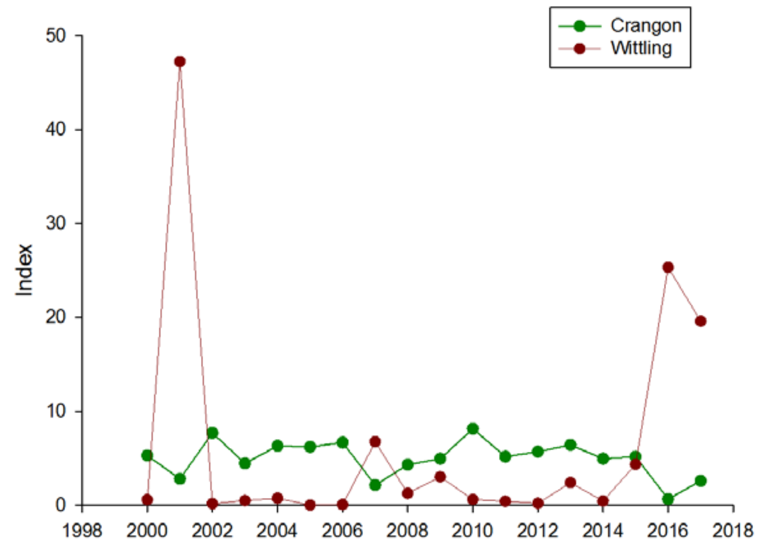


Figure 16. ***Crangon crangon*** **and whiting abundance indices (Schleswig Holstein Coast) obtained by the German DYFS survey.**

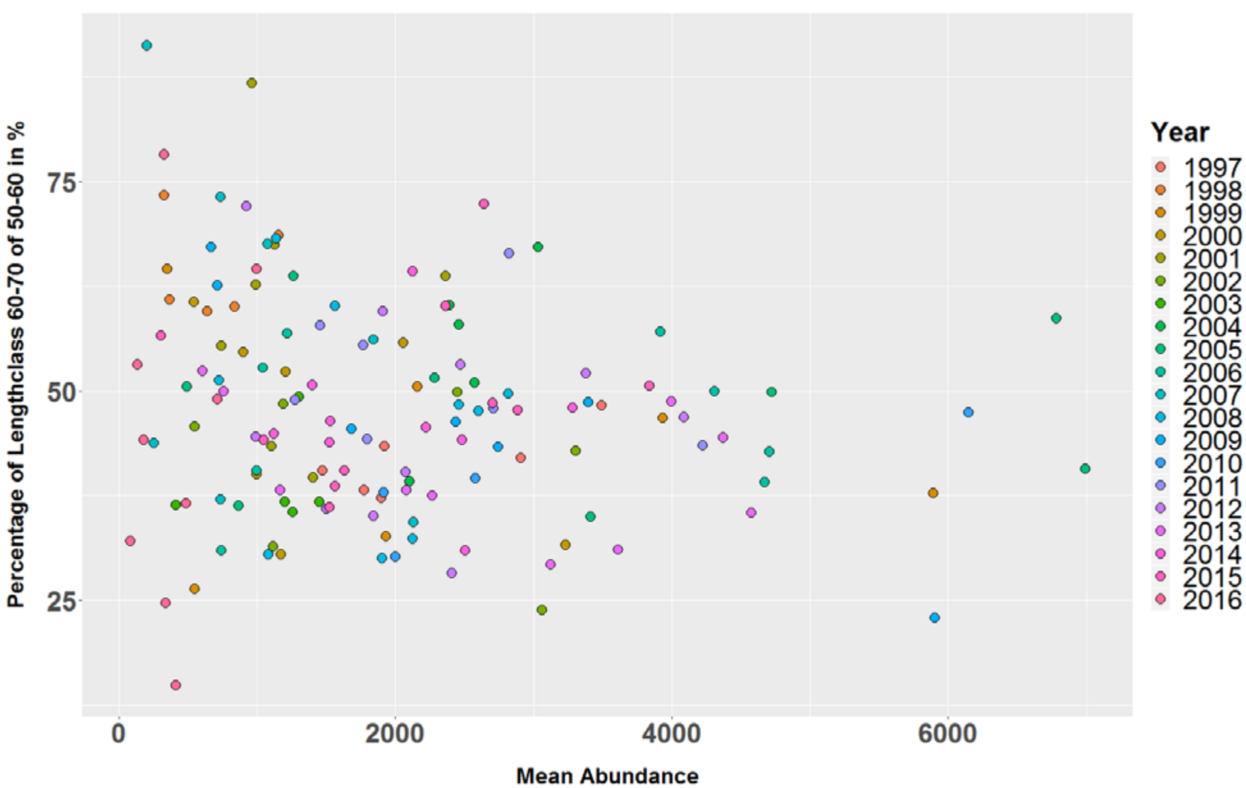


Figure 17. Percentage of abundance of the 60–70 mm length class in relation to the abundance of the 50–60 mm length class plotted on the mean density of shrimp (number of individuals fished per 15 min). Different colours illustrate different years; for each year there are several data points referring to the different sub-areas of the DYFS survey.

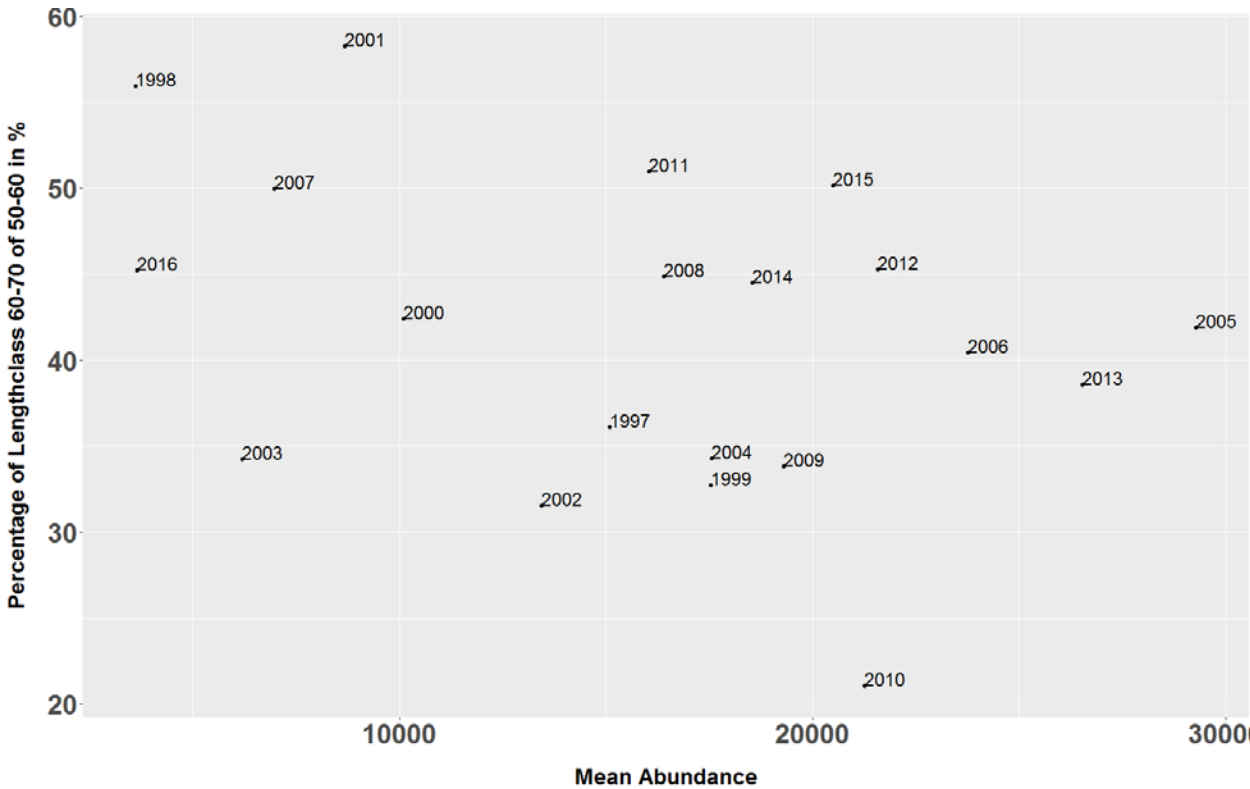


Figure 18. Percentage of abundance of the 60–70 mm length class in relation to the abundance of the 50–60 mm length class plotted on the mean density of shrimp (number of individuals fished per 15 min). All data from different sub-areas of the same year are combined here into one data point.

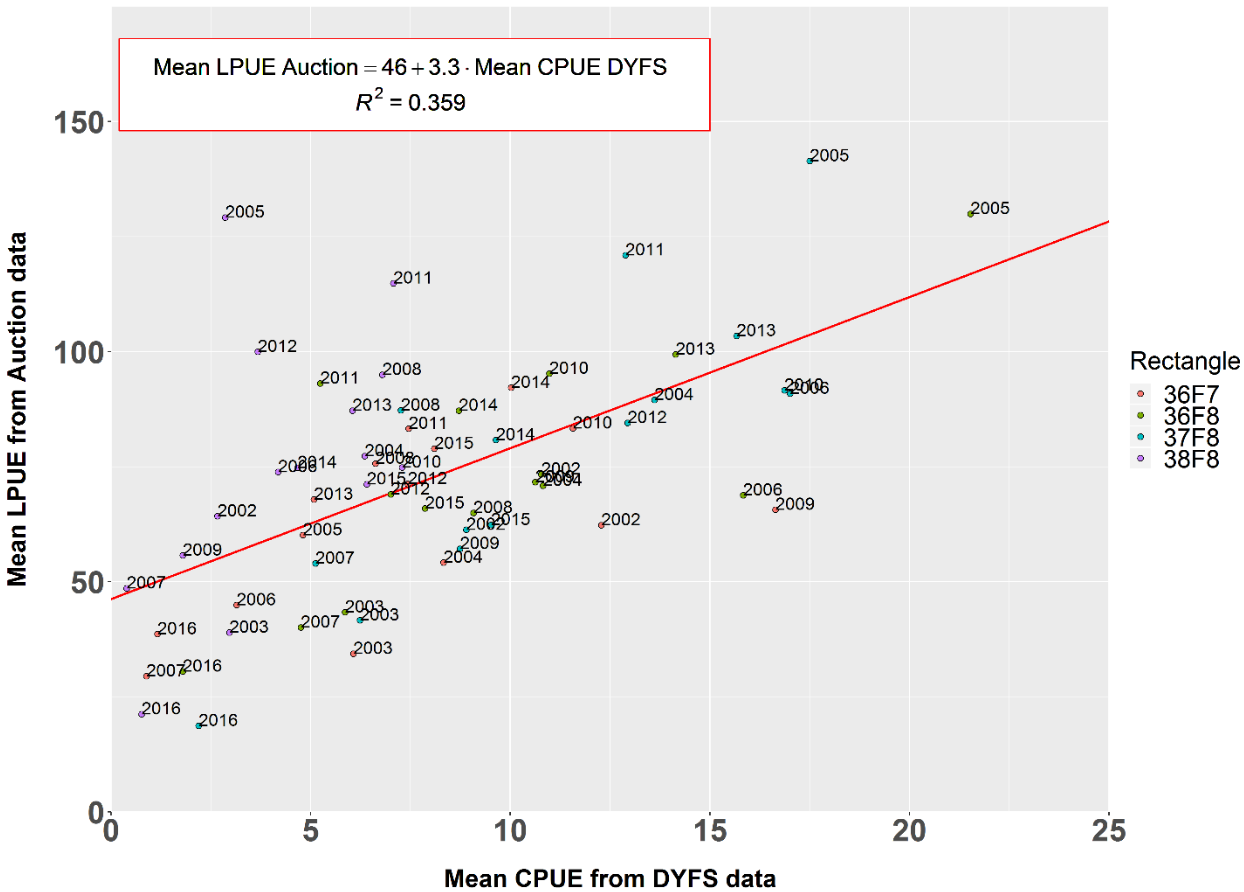


Figure 19. Relationship between the weight of commercial shrimp in kg/h from the DYFS and mean commercial LPUE (kg/h) from each rectangle (landing declaration data). Red line illustrates the linear regression.

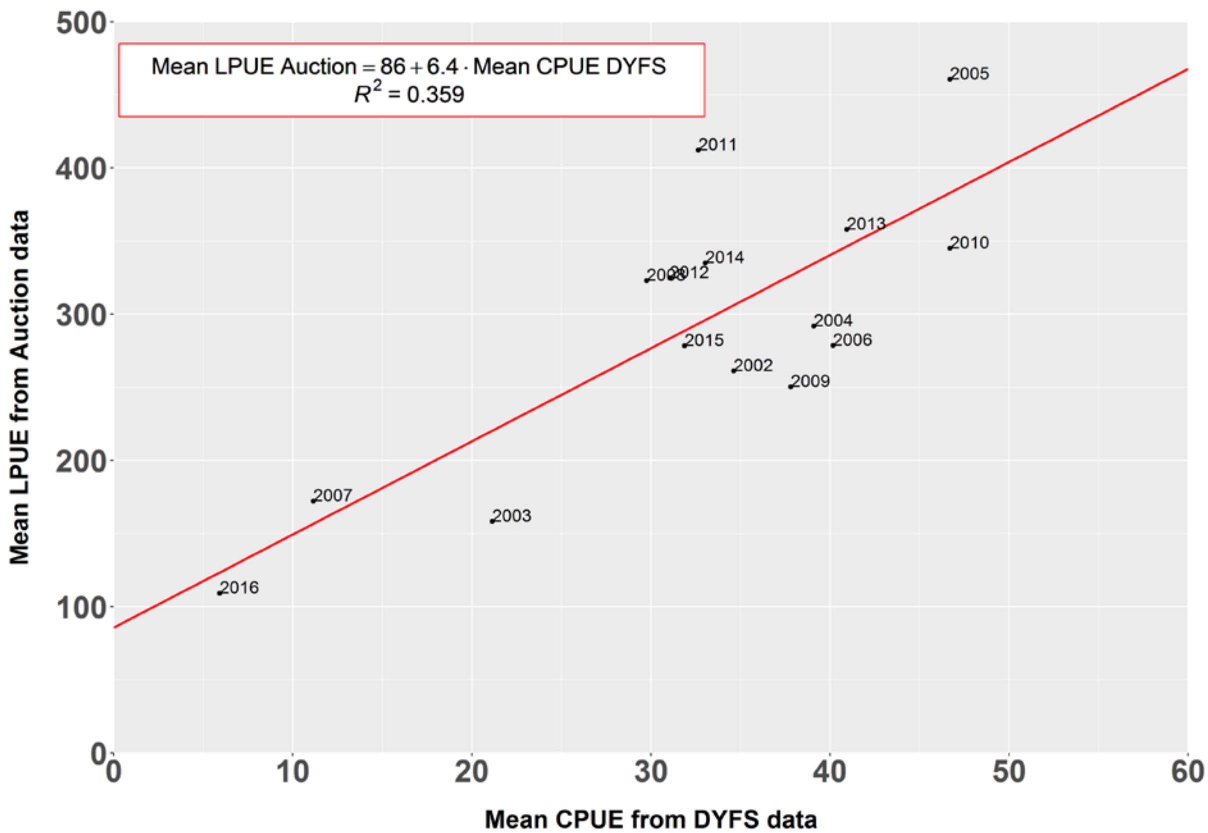


Figure 20. Relationship between the weight of commercial shrimp in kg/h from the DYFS and mean commercial LPUE (kg/h) (landing declaration data). Red line illustrates the linear regression.

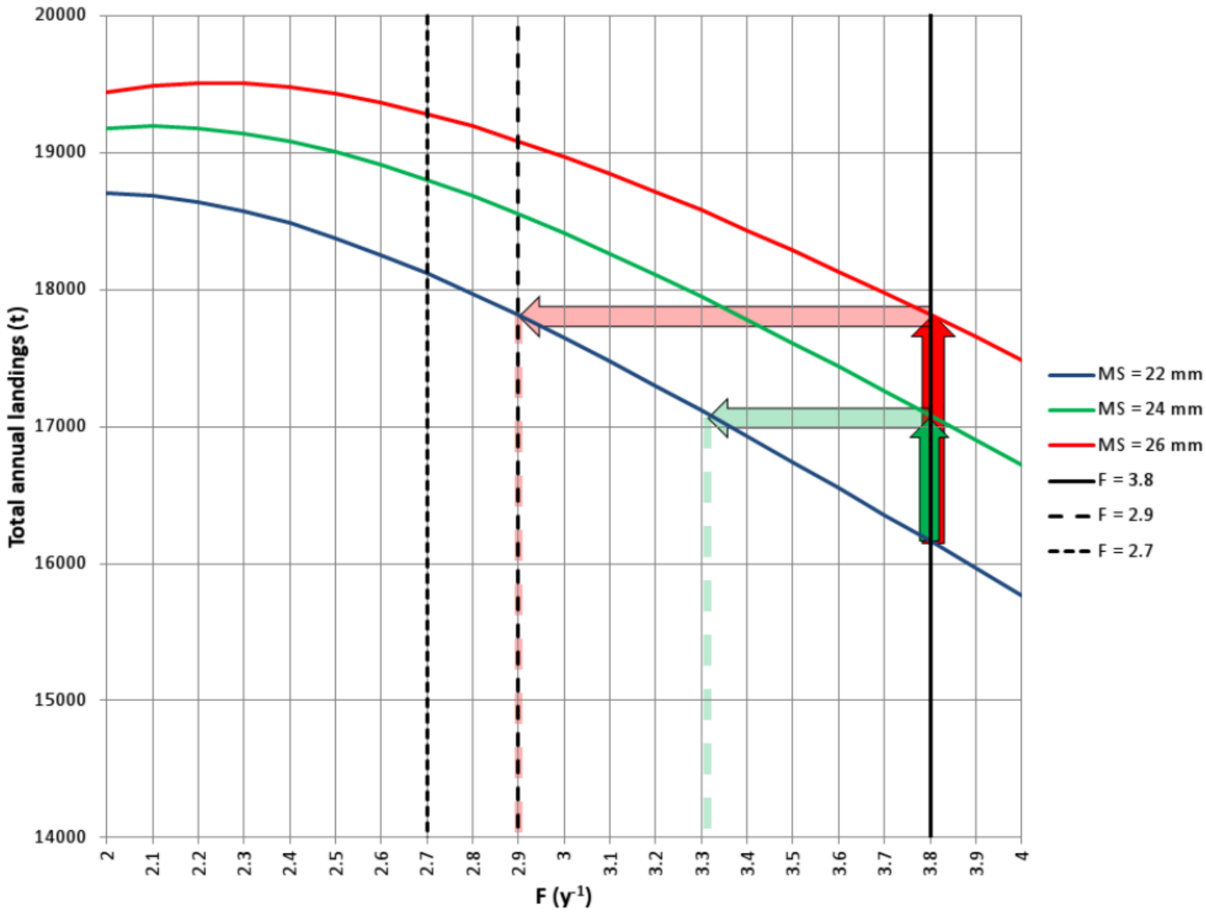


Figure 21. Total annual landings versus fishing mortality of simulation model runs for mesh sizes scheduled in the management plan (22, 24, and 26 mm). The blue line corresponds to the present mesh size (22 mm). The vertical black line indicates the present fishing mortality (Temming & Hufnagl 2015). Dashed vertical black lines mark fishing mortalities that would have resulted when the weekends in 2016 were closed for fishing (F = 2.7 for a closure from Friday to Sunday and F = 2.9 for a closure from Saturday to Sunday). Vertical arrows: increase in landings simulated for a 2 or 4 mm mesh size increase. Horizontal arrows: reduction of fishing effort that is needed to reach the same effects than a mesh size increase.

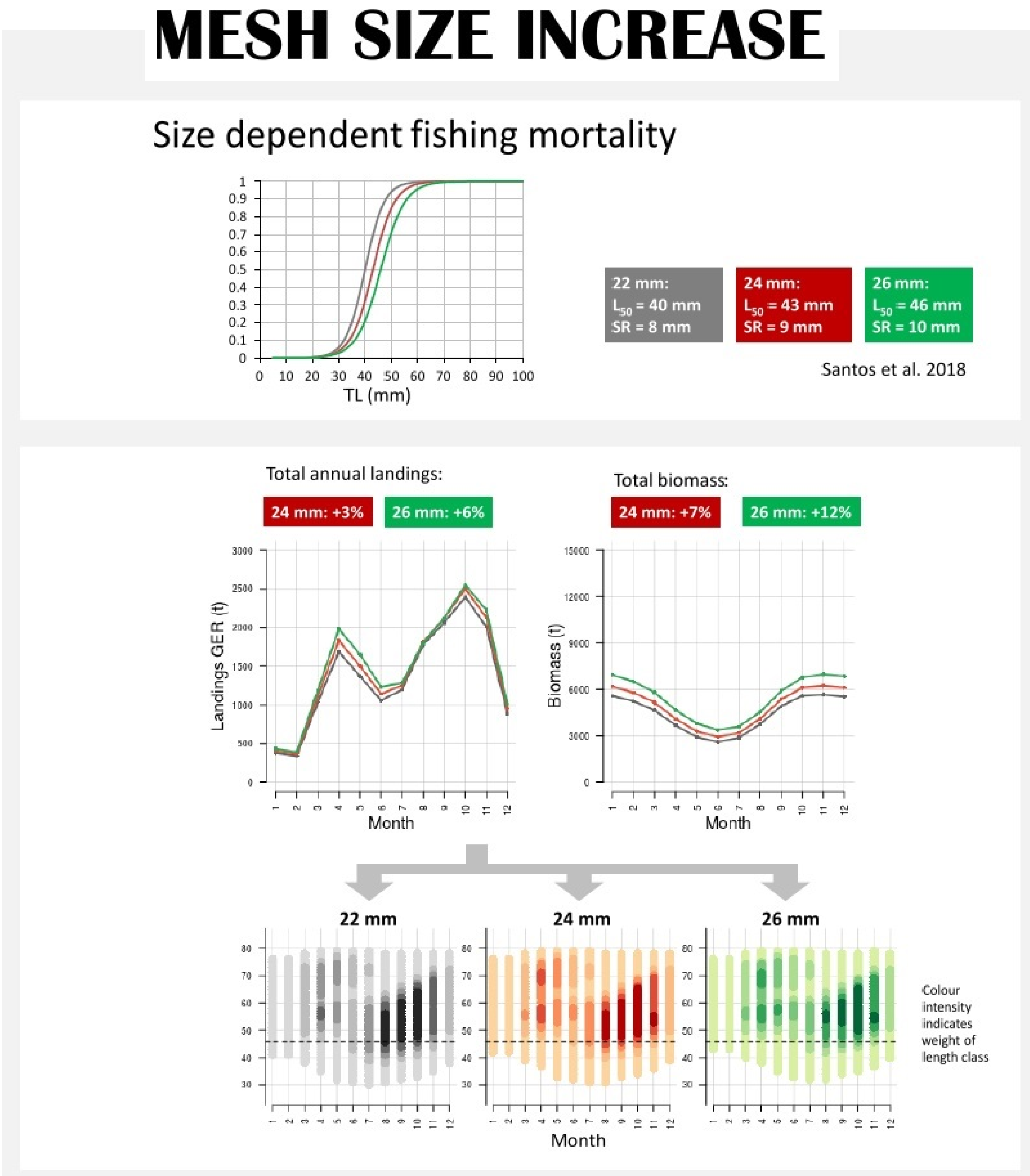


Figure 22. Effects on biomass, landings and size frequency distribution resulting from the management option "mesh size increase" as derived from the simulation model outputs. The results are based on data for the German Brown shrimp fleet and cannot be readily extrapolated to other fleets.

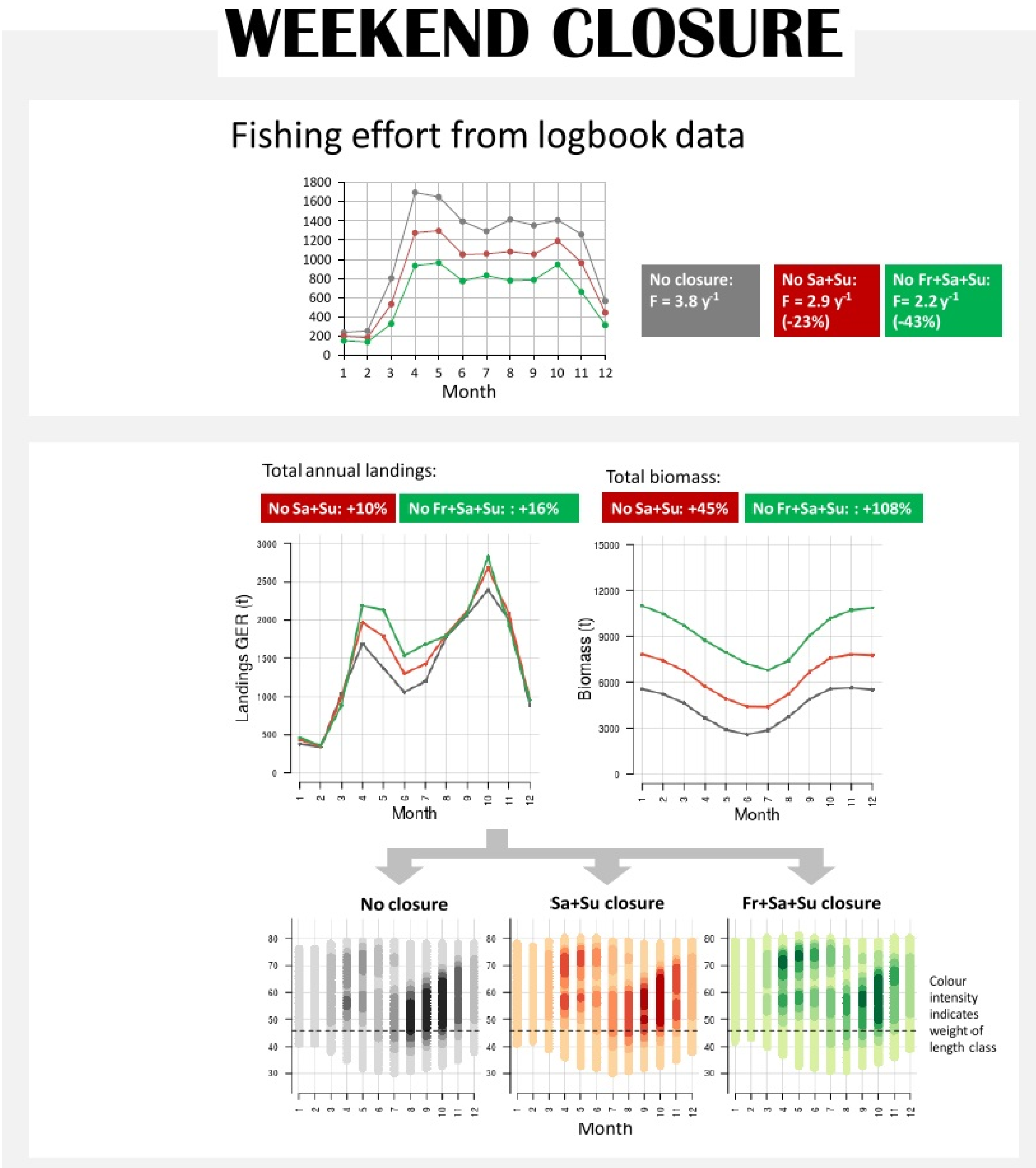


Figure 23. Effects on biomass, landings and size frequency distribution resulting from the management option "Weekend closure" as derived from the simulation model outputs. The results are based on data for the German Brown shrimp fleet and cannot be readily extrapolated to other fleets.

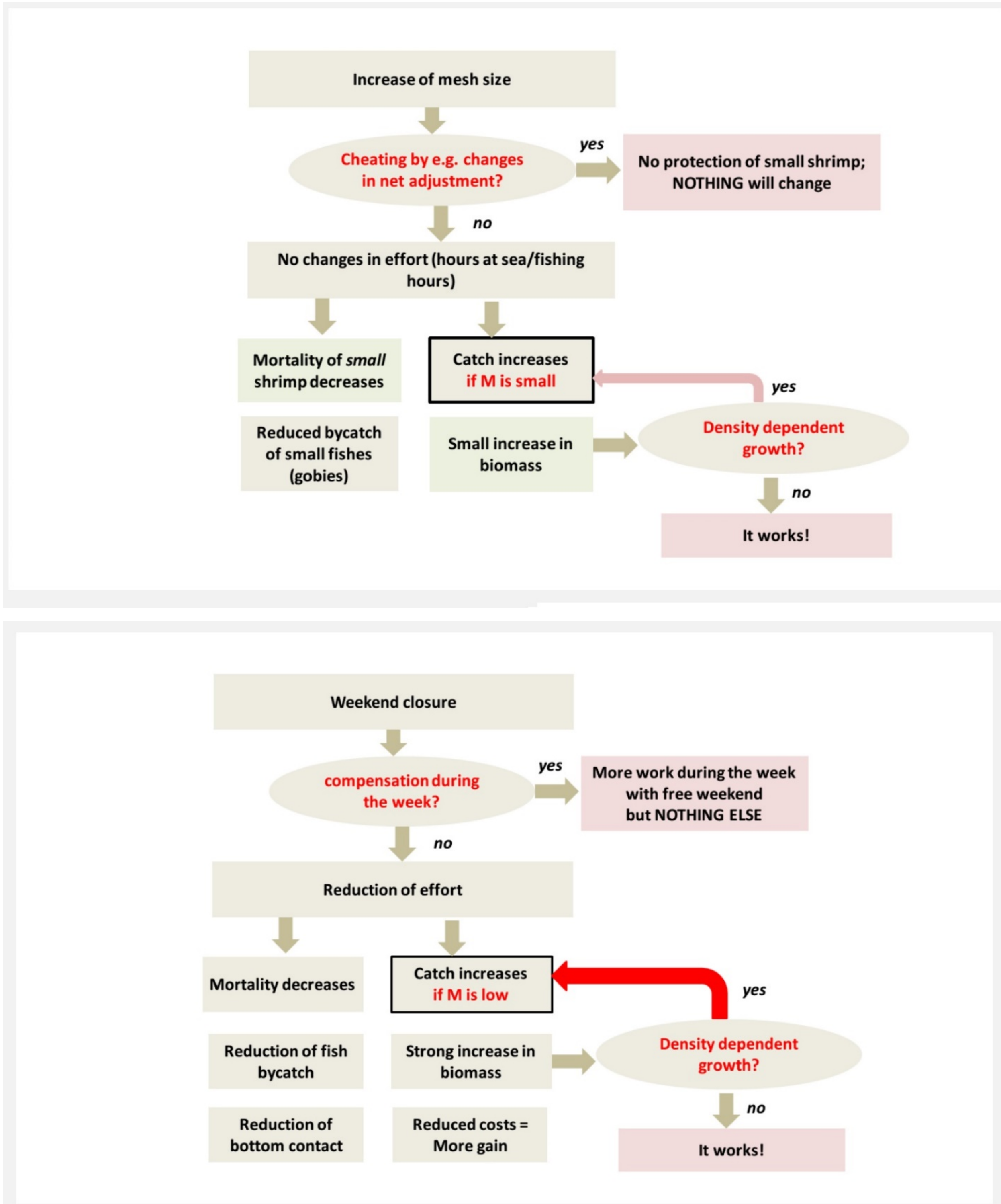


Figure 24. Requirements and benefits of the management option "mesh size increase" (upper panel) compared to "Weekend closure" (lower panel).

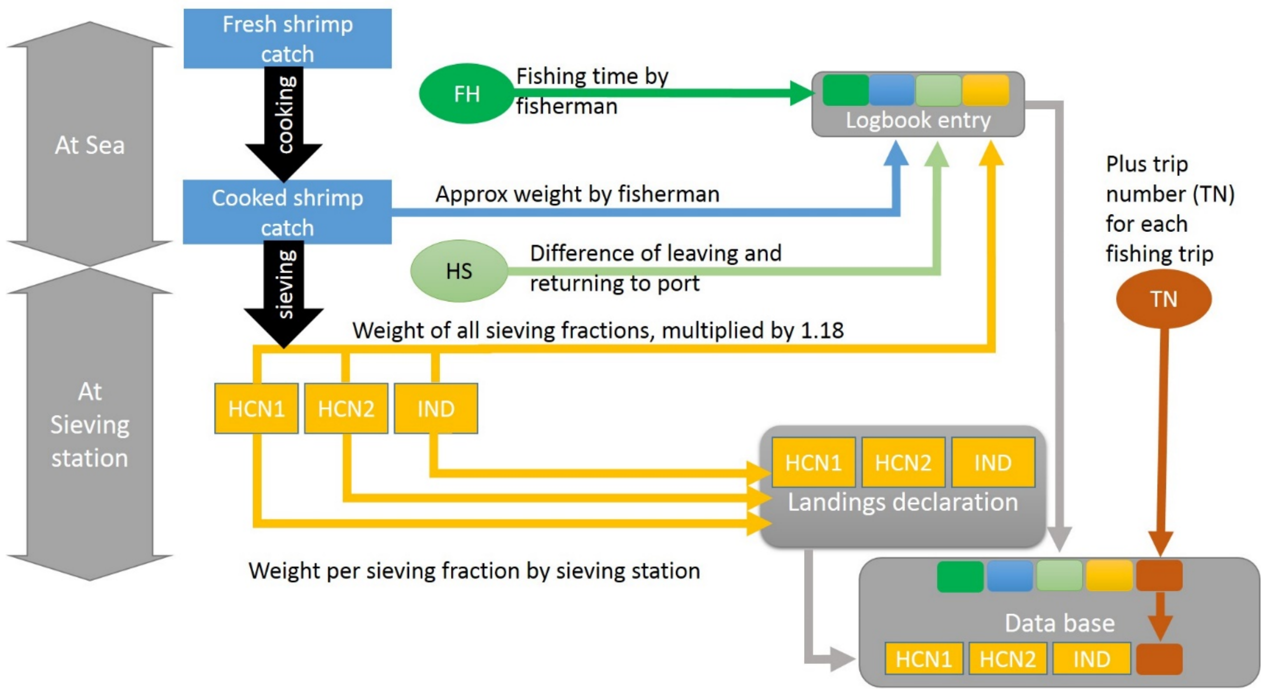
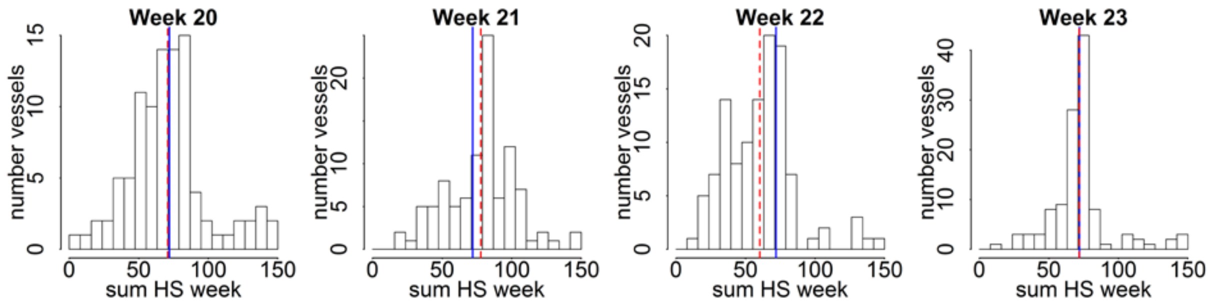


Figure 25. Data collection process for logbook and landing declaration data. For graphical purposes, only the three most important sieving fractions (HCN 1 and 2, IND) are displayed. "IND" marks undersized shrimp which are not declared for human consumption, while "HCN" are shrimps in two different size classes (HCN 1 and HCN 2) for human consumption. The weight of all sieving fractions multiplied by 1.18 is often referred to as "back-calculated fresh weight".

Netherlands:



Germany:

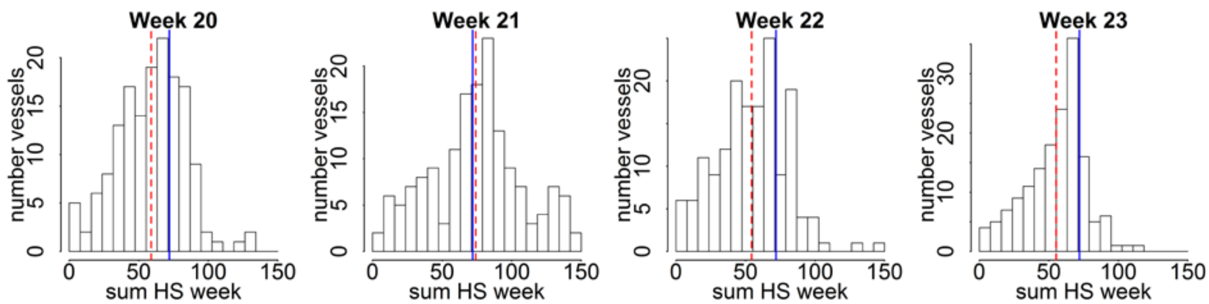


Figure 26. Sum of HS per vessel and week in 2016 from week 20 to week 23. The effort was restricted to 72 HS per week and vessel in week 22 and week 23. The red line displays the mean effort per week and vessel in HS; the blue line marks 72 HS per week and vessel. Some of the very high values (> 150 HS) are excluded from the figure for graphical purposes.

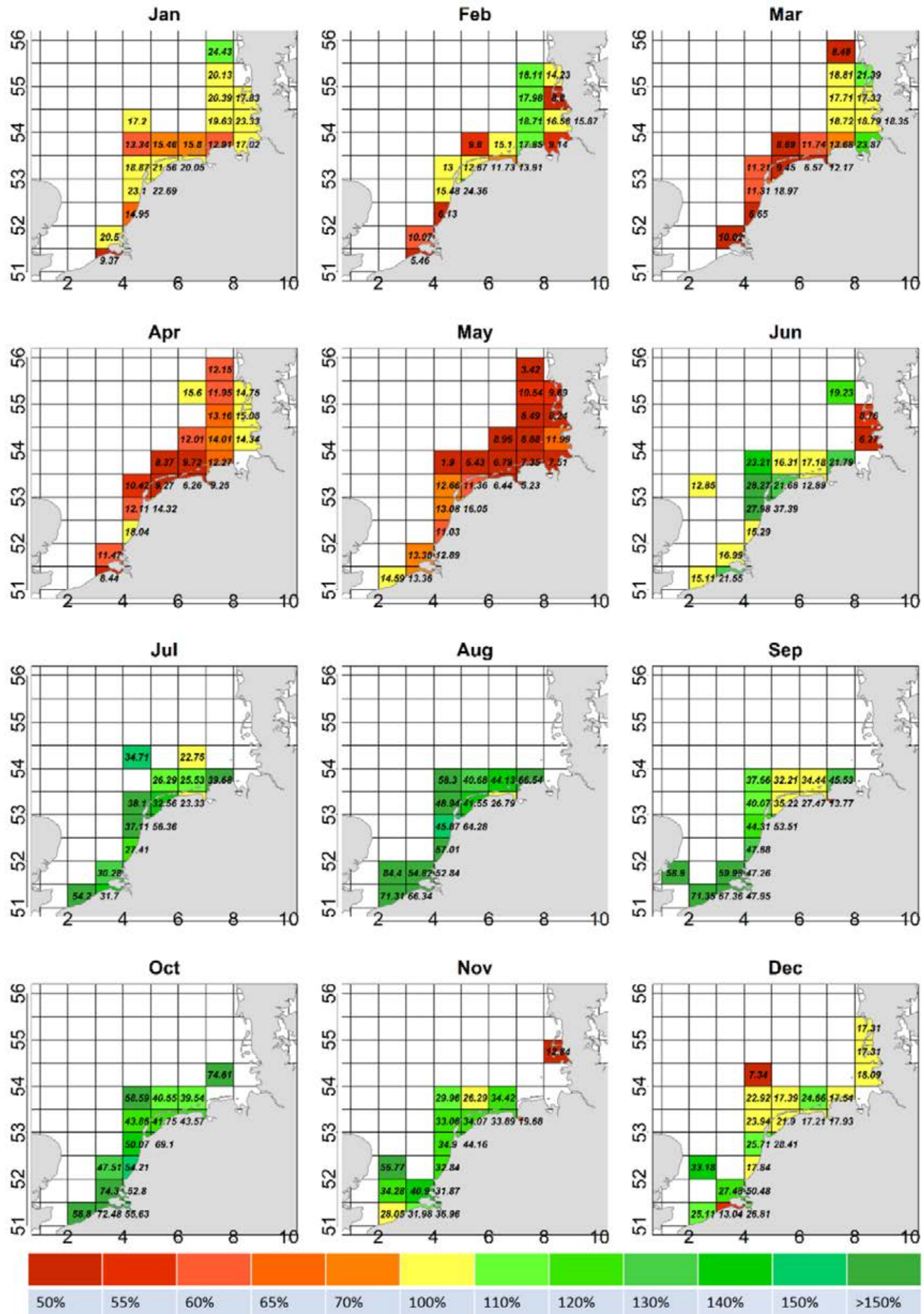


Figure 27. Spatial LPUE$_{NL}$ distribution in kg/HS in 2016 for the Dutch Brown shrimp fleet. Numbers in black show the mean LPUE for the respective rectangle and Month. Colors as shown in legend represent levels of the corresponding Ref$_{NL}$ (see Table 3).

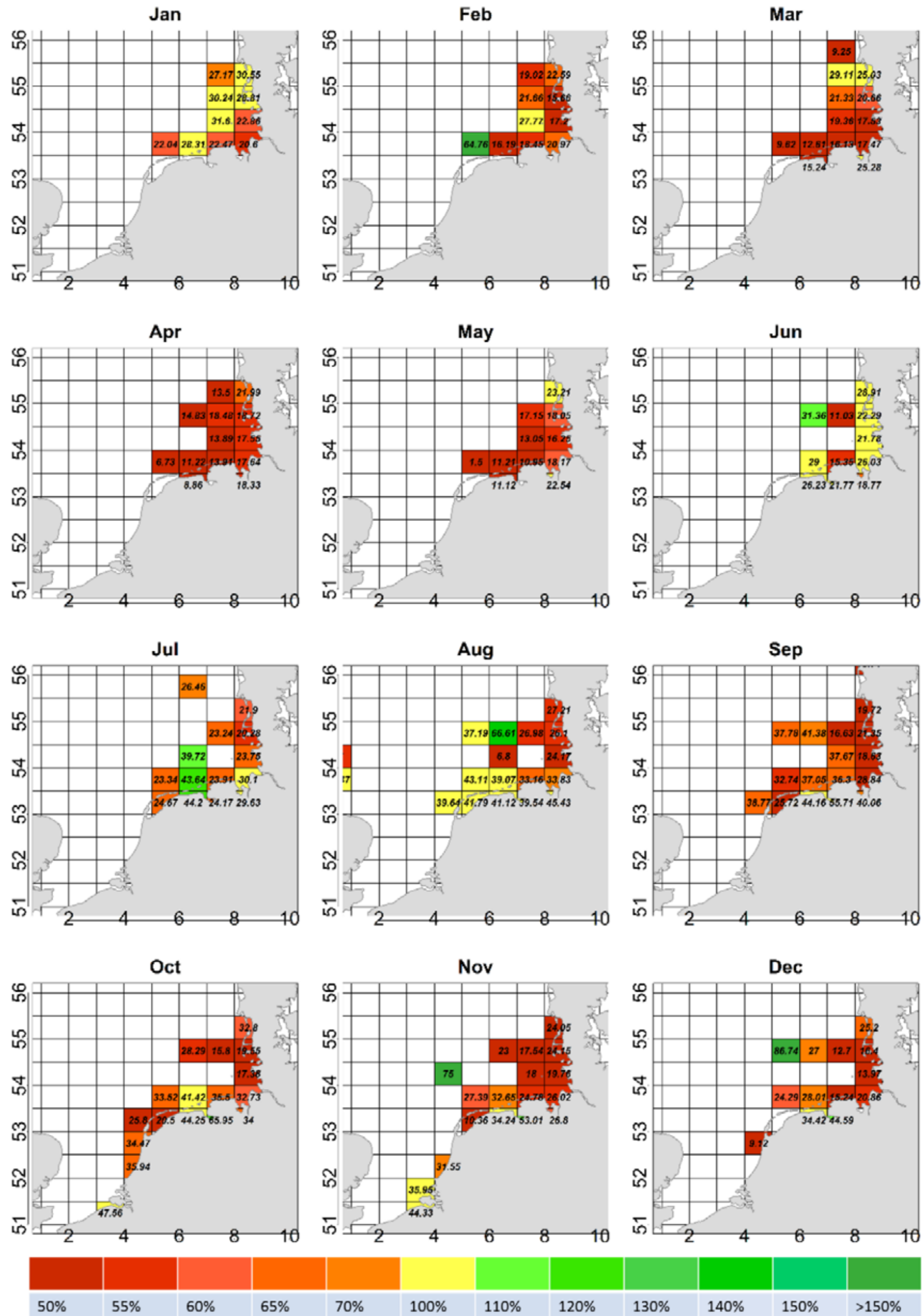


Figure 28. Spatial LPUE$_D$ distribution in kg/FH in 2016 for the German Brown shrimp fleet. Numbers in black show the mean LPUE for the respective rectangle and Month. Colors as shown in legend represent levels of the corresponding Ref$_D$ (see Table 3).

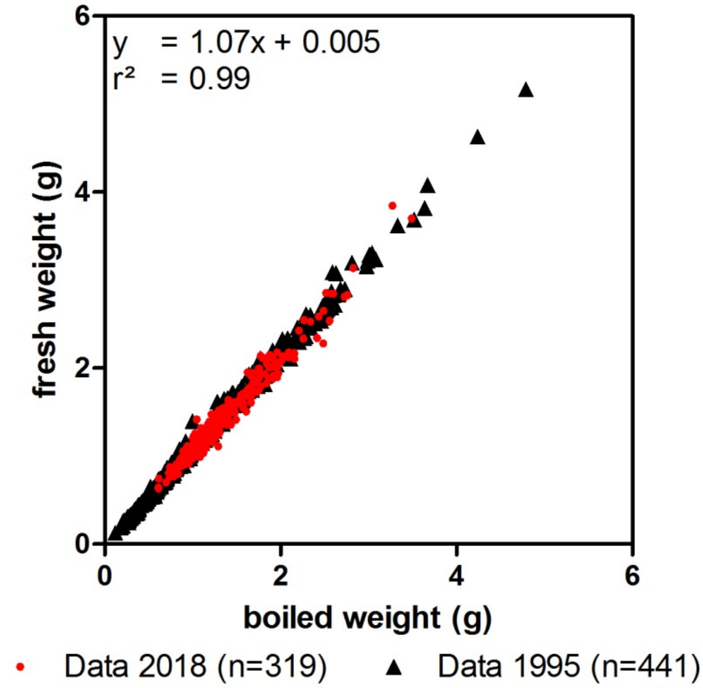


Figure 29. Fresh versus boiled weight of brown shrimp *Crangon crangon*. Red dots = measurements of K. Hünerlage (2018 Thünen Institute, unpublished); black triangles = measurements of S. Riemann (1995 Thünen Institute, unpublished); n = number of individuals measured.

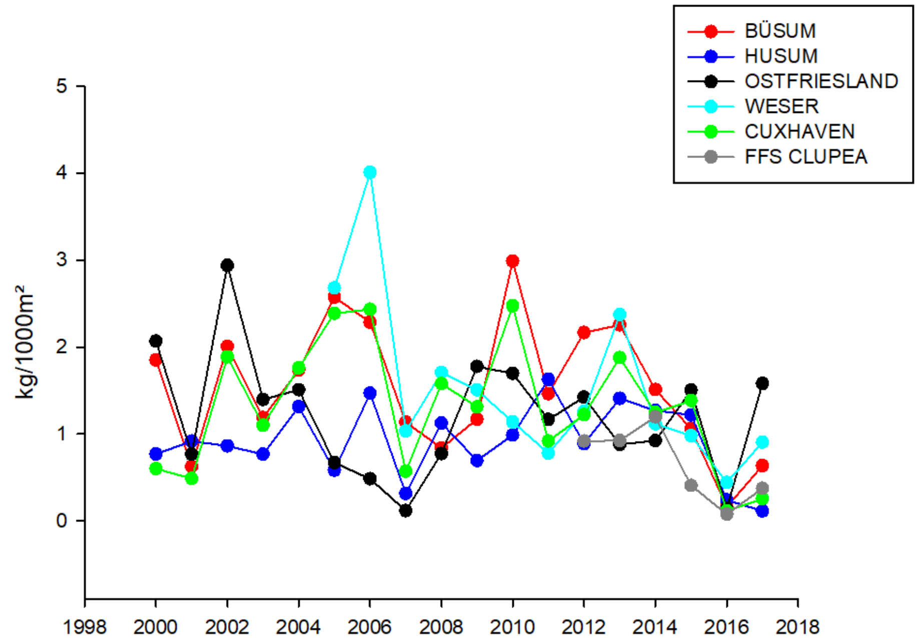


Figure 30. ***Crangon crangon*** **abundance indices for the different German survey areas from 2000–2017.**

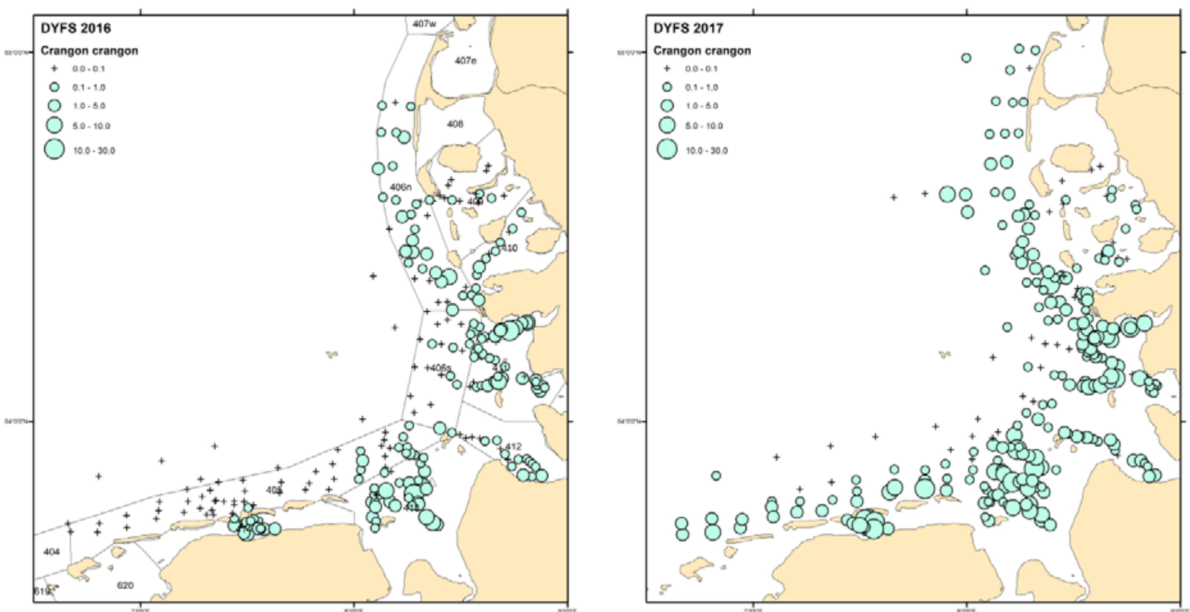


Figure 31. The distribution of ***Crangon crangon*** **in the German Bight in 2016 (left panel) and 2017 (right panel) obtained by the German DYFS.**

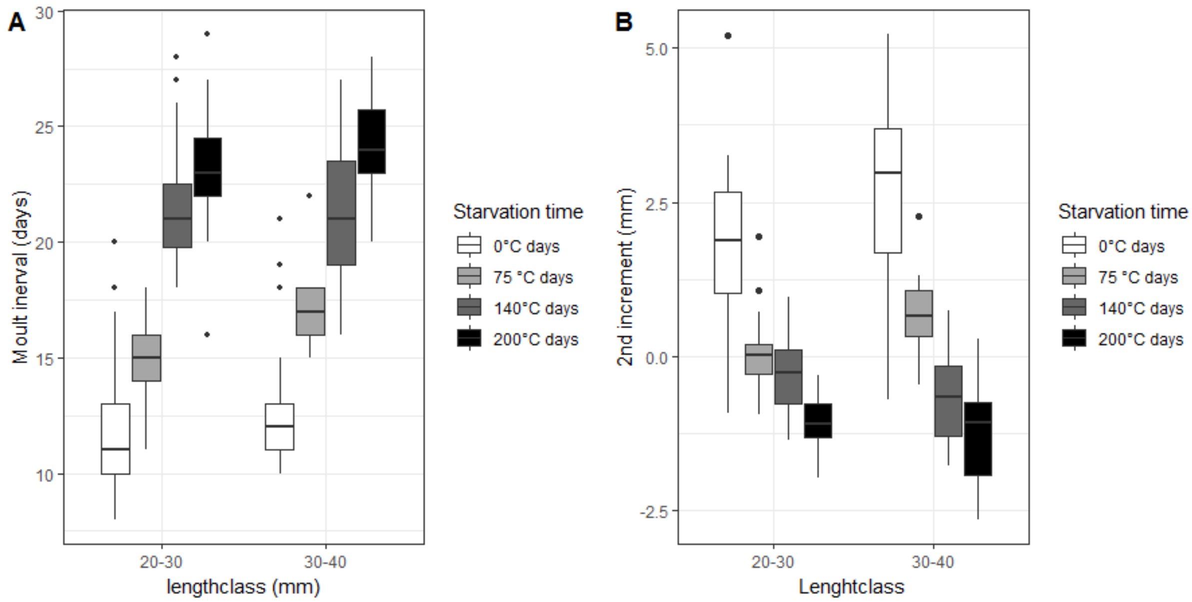


Figure 32. A) Moult interval (days) over starvation period and length class. B) Growth increment (mm) over starvation period and length class.

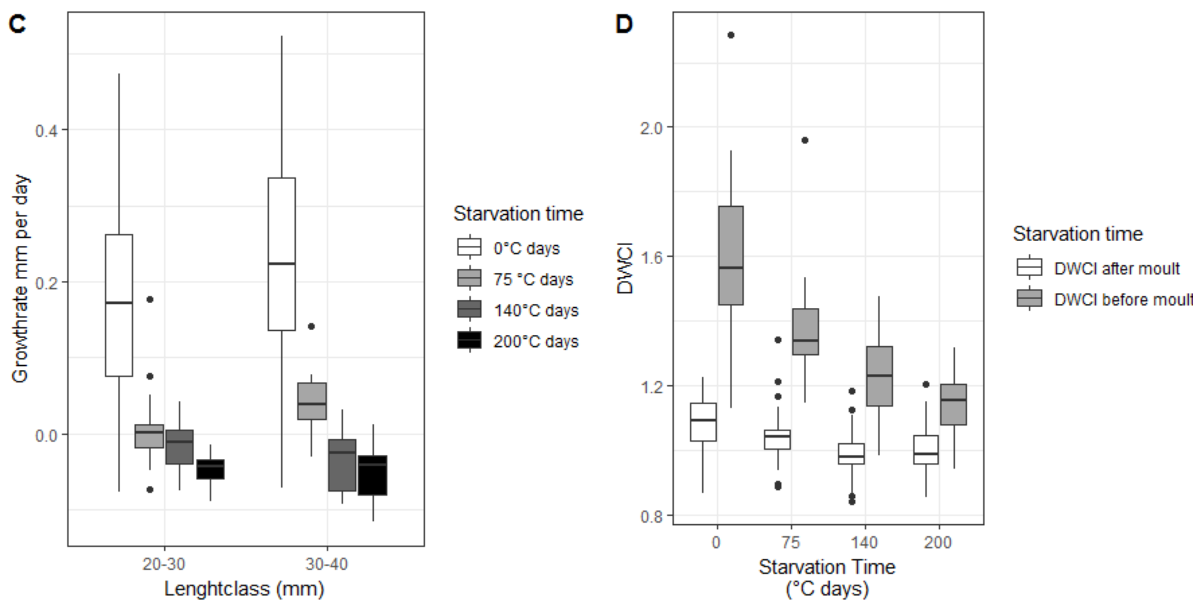


Figure 33. C) Growth rate (mm · day $^{-1}$) over starvation period and length class. D) Pre- and post moult condition over starvation time (°C days).

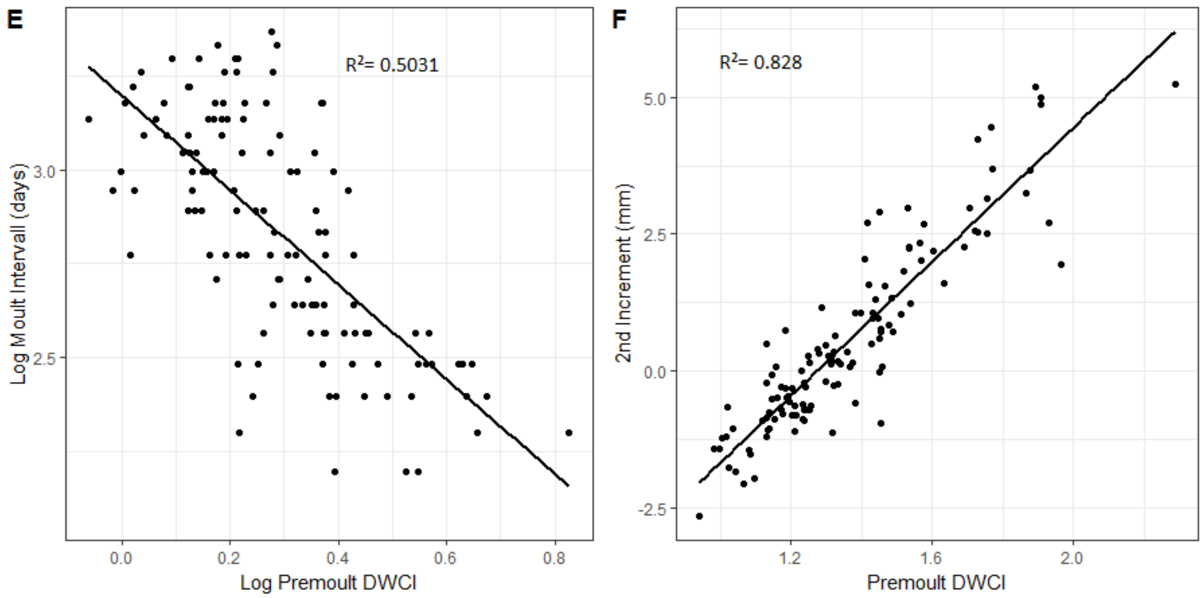


Figure 34. E) Log- transformed moult interval (days) over log transformed pre-moult condition. F) Growth increment after moult (mm) over pre moult condition.

References (Annex 5)

Hufnagl, M., A. Temming, *et al.* (2010). "Estimating total mortality and asymptotic length of *Crangon crangon* between 1955 and 2006." Ices Journal of Marine Science 67(5): 875-884.

Tulp, I., C. Chen, *et al.* (2016). "Annual brown shrimp (*Crangon crangon*) biomass production in Northwestern Europe contrasted to annual landings." ICES Journal of Marine Science. doi:10.1093/icesjms/fsw141.