ICES Journal of Marine Science, 2023, Vol. 82, Issue 3, fsad124
https://doi.org/10.1093/icesjms/fsad124
Received: 3 February 2023; **revised:** 2 July 2023; **accepted:** 4 July 2023
Food for Thought

ICES CIEM
International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

The rapid expansion of offshore wind farms challenges the reliability of ICES-coordinated fish surveys—insights from the Baltic Sea

S. Haase [1,*], C. von Dorrien [1], O. Kaljuste [2], N. Plantener [1], E. Sepp [3], V. Stelzenmüller [4], A. Velasco [1], D. Oesterwind [1]

[1]Thünen Institute of Baltic Sea Fisheries, Alter Hafen Süd 2,18069 Rostock, Germany
[2]Department of Aquatic Resources, Institute of Coastal Research, Swedish University of Agricultural Sciences, Skolgatan 6, 74242 Öregrund, Sweden
[3]Estonian Marine Institute, Vanemuise 46a, 51014 Tartu, Estonia
[4]Thünen Institute of Sea Fisheries, Herwigstraße 31, 27572 Bremerhaven, Germany
* *Corresponding author: tel: +49 381 66099 121;* e-mail: stefanie.haase@thuenen.de.

Abstract

Fish stock assessment and sustainable management requires that the whole distribution area of the managed fish stocks is representatively sampled. Along with an increasing demand for renewable energy in Europe, a growing number of areas are allocated for current and future offshore wind farms (OWF). Besides various unknown environmental effects, impacts on different stakeholder activities, such as fisheries, are considered during the implementation process. Scientific interests and tasks are, however, often marginalized. The current ban of commercial fisheries and fisheries monitoring in OWFs, in combination with an increase of OWF areas and habitat alteration within OWFs, might therefore bias the time series of scientific surveys and, thus, fisheries stock assessments. The expected increase in the overlap between OWFs and scientific fish surveys coordinated by the International Council for the Exploration of the Sea (ICES) in the Baltic Sea could result in, depending on the survey, up to 6.6–11.5% of the stations and transects being unavailable for sampling. We discuss the potential consequences for survey time series and stock assessments. Further, we aim to stimulate the discussion about the future of current standard surveys in the context of rapid expansions of OWFs, including the need for adaptations in survey design.

Keywords: Baltic Sea; demersal trawl surveys; hydroacoustic surveys; ICES-coordinated surveys; offshore wind parks; survey alternatives

The potential conflict between OWFs and fisheries research

The European Union (EU) aims to become climate neutral by 2050 ["European Green Deal"; COM(2019) 640 final], which results in an increasing demand for renewable energies, such as wind energy. Renewable offshore wind energy is targeted to reach 60 GW by 2030 and 340 GW in all EU sea basins by 2050 [2021/2012(INI)]. The increasing demand for available space for offshore wind farms (OWF) results in increasing conflicts between various stakeholders, such as fishery, shipping, military, and nature conservation. Around the globe, maritime spatial planning has been implemented to primarily mitigate spatial use conflicts and balance the different interests of stakeholders. In order to evaluate the effect of large infrastructure projects, such as OWFs, on the environment, EU legislation stipulates that an environmental assessment (EA) is carried out, where all stakeholders within and beyond national borders must be included in the process for consultation already at an early stage.

Besides ecological consequences, the main focus of the EA lies on the socio-economic values of various sectors. Currently, the value of scientific interests, namely the establishment of a sound scientific basis for the assessment of ecosystem functions and processes, is difficult to quantify. They are therefore often not fully considered. This is, among others, the case for fisheries research. The assessment of commercially exploited fish stocks is a core task of fisheries science to advise on sustainable management and use of living resources. Thus, data series from the commercial fishery, so-called fisheries-dependent data, and long time series of fisheries-independent survey data provide the key pillars for fisheries assessments and the sustainable management of fish stocks (Gallo *et al.*, 2022). Due to the heterogeneous distribution of many fish stocks, large areas have to be covered by fisheries-independent surveys in a relatively short period of time. Therefore, internationally coordinated fisheries research cruises are performed in parallel to ensure a standard survey design across nations and years.

As in other European areas, more and more areas are being allocated to OWFs in the Baltic. Currently, OWFs in the Baltic are excluded from co-use, meaning that other users, such as the fishery, but also the standardized fisheries research cruises cannot be performed in these areas. While the loss of fishing areas due to OWFs has been widely discussed in public and science for the Baltic Sea (e.g. Stelzenmüller *et al.*, 2022) and other areas (e.g. Schupp *et al.*, 2021; Steins *et al.*, 2021; Stokesbury *et al.*, 2022), the influence of OWFs on scientific fisheries surveys has had so far little attention (but see Hare

Table 1. Overview of the ICES-coordinated fish surveys in the Baltic Sea.

Category	Survey	Start of index	Method	Target species
Demersal	Baltic International Trawl Survey (BITS)	1991	(i) Bottom trawling (ii) CTD stations	demersal species, such as cod, flounder, plaice, turbot, dab, brill
Acoustic	Baltic Acoustic Spring Survey (BASS)	2001	(i) Hydroacoustic measurements	pelagic species, mainly herring and sprat
	Baltic International Acoustic Survey (BIAS)	1991	(ii) Pelagic trawling (iii) CTD stations	

et al., 2022). Reduction and reallocation of survey effort as a result of areas being unavailable to carry out fisheries surveys and an alteration of unmonitored habitat might lead to an incomplete coverage of the stock distribution areas and consequently to an inaccurate or biased estimate of stock status with extensive economical and nutritional consequences for the fishing sector and the general public (ICES, 2020, 2023).

Fisheries surveys used for stock assessment in the Baltic Sea are internationally coordinated by the Baltic International Fish Survey Working Group of the International Council for the Exploration of the Sea (ICES). The survey results are used to calculate relative stock indices for many commercially exploited fish stocks. OWFs, which are currently in operation, have already led to smaller modifications of the surveys in the past and highlighted the need to analyse the implications for the future.

Here, we use the Baltic Sea as a case study and quantify the current and planned future spatial overlap of the two acoustic surveys: Baltic Acoustic Spring Survey (BASS) and Baltic International Acoustic Survey (BIAS) as well as the biannual demersal Baltic International Trawl Survey (BITS) with OWFs. Finally, we present three practical steps to account for the loss of survey areas in the future.

Material and methods

Extracting survey activities from the demersal and acoustic surveys

Survey data have been derived from three main international surveys regularly carried out in the Baltic Sea used for the stock assessment of pelagic and demersal species (Table 1). The surveys are internationally coordinated by the ICES Working Group on Baltic International Fish Surveys (WGBIFS). This group delivers an annual survey index for each age or length class and species combination to the stock assessment. Although this index is not spatially resolved, the survey is conducted and estimated in spatially smaller units: (i) ICES statistical rectangles which represent a grid with latitudinal intervals of 30′ and longitudinal intervals of 1° and (ii) ICES subdivisions (SDs), which represent larger management units consisting of several ICES rectangles.

The main objective of the demersal Baltic International Trawl Survey (BITS), conducted biannually in February–March and November, is to determine the catch per unit effort of the commercially important demersal fish species in the Baltic Sea (i.e. cod, plaice, flounder, dab, turbot, and brill; ICES, 2017a). During the BITS, ∼560 stations per year are sampled with bottom trawling by up to eight neighbouring countries of the Baltic Sea. Before every BITS survey, the fishing stations are randomly selected in depth-stratified layers from a database for approved BITS haul tracks (TowDatabase), which currently comprises 783 tracks. All 783 BITS stations were used in the following analysis and are available in the ICES database of trawl surveys (DATRAS; https://www.ices.dk/data/data-portals/Pages/DATRAS.aspx).

The acoustic surveys are conducted once a year. The "Baltic Acoustic Spring Survey (BASS)" is performed in May by up to seven countries, while the "Baltic International Acoustic Survey (BIAS)" is performed in September/October by up to nine countries. Each statistical rectangle should be covered by at least 60 nautical miles of hydroacoustic measurements per area of 1000 nm^2 and transects should cover the area uniformly. The exact allocation of acoustic transects can slightly vary between years due to restrictions imposed by the national authorities and agreements within WGBIFS. Within this study, the tracks have been extracted for the year 2020 from the ICES database for acoustic trawl surveys (www.ices.dk/data/data-portals/Pages/acoustic.aspx) because this year showed a usual area coverage (ICES, 2021a; COVID-19 did not have an impact on the survey effort). Tracks are provided as logged GPS positions for each covered nautical mile distance during the survey and uploaded annually by the member countries. During the acoustic surveys, pelagic trawl hauls complement the acoustic signal to estimate the species compositions, length distributions, age structures, individual weights, maturity ogives, and sex proportions. Fishing hauls are not pre-defined and are conducted when sufficient acoustic echo is visible, however, it is aimed to conduct at least two fishing hauls per ICES statistical rectangle (ICES, 2017b). The fishing hauls from the acoustic surveys are not further examined in this study as they vary between years, are conducted based on the expert opinion of the cruise leader, and are therefore much more flexible to adapt to new areas that are no longer accessible.

Analysing offshore wind park data

Global data on current and planned future OWFs were obtained from 4C Offshore Ltd (https://map.4coffshore.com/offshorewind, accessed 28 April 2022). The dataset covers all OWF projects with spatial as well as status information regarding the project progress from pre-planning to fully commissioned. The dataset is limited to OWFs and does not include associated infrastructure such as cable corridors. Following Stelzenmüller *et al.* (2022), we classified the dataset based on the starting year into three different temporal scenarios: (i) "present" (2022), (ii) "mid-term" (2023–2025), and (iii) "long-term" (>2025). For OWFs with no information on the starting date, the respective scenario was interpolated based on category (followed Stelzenmüller *et al.*, 2022). The statuses "failed", "dormant", "cancelled", or "decom-

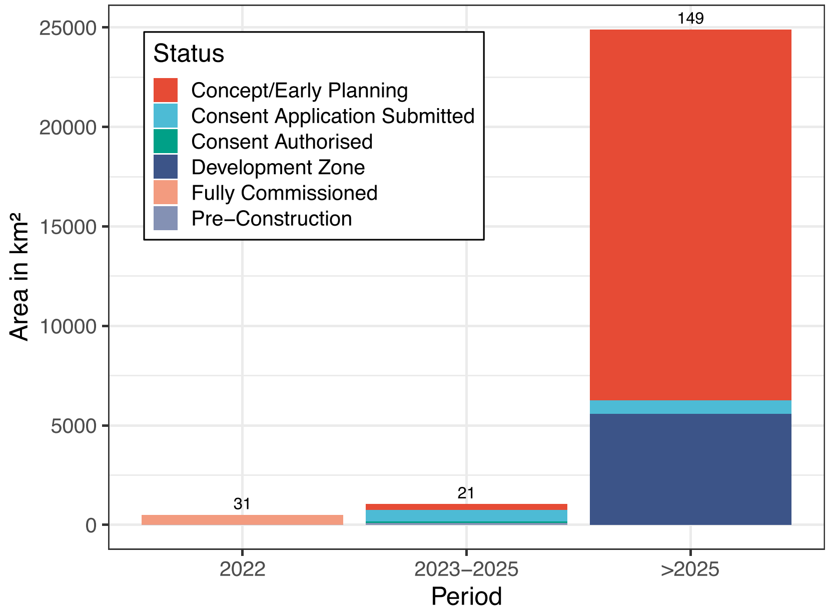

Figure 1. Surface area of offshore windfarms at present (2022), and additional areas in the mid-term (2023–2025) and long-term (>2025). Colours represent the different planning stages. The numbers above the bars represent the aggregated total numbers of OWF of the different categories in that period. All numbers refer to the current planning status in 2022.

missioned" were excluded from the dataset. Note that the scenario "long-term" involves uncertainty about which percentage of the OWFs are actually commissioned in the end and some OWFs overlap in area. This scenario thus might show an exaggerated estimate of areas being allocated for OWFs.

Estimating the impact of wind farm activities on BITS, BIAS, and BASS

To assess the impact of OWFs on ICES-coordinated demersal and acoustic surveys in the Baltic at (i) present, (ii) mid-term, and (iii) long-term, we quantified the overlap of survey activities and OWF areas. Currently, OWFs in the Baltic Sea contain navigation bans and therefore also fisheries research is prohibited. Transect lengths and the number of stations within the OWFs were extracted separately for each temporal scenario with ArcGIS (10.6) using the tool "Spatial Join" in the Overlay toolset.

For the acoustic surveys, we aggregated the transect length within OWF polygons per ICES statistical rectangle. For BITS, we quantified the number of fishery stations within OWF polygons, which were aggregated per ICES rectangle and depth strata as defined in the BITS manual (ICES, 2017a). The affected transect length and number of stations was estimated by dividing the total transect length and number of stations by the length and number of stations within the OWFs, respectively.

Results

The development of OWFs in the Baltic Sea

The scenario "present" includes 31 OWFs with a spatial expansion of 495.4 km^2 in the Baltic Sea (Figure 1). They are solely distributed in close proximities to the German, Danish, and Swedish coasts in the southern Baltic Sea (Figure 3). The spatial coverage is increasing by 1035.8 km^2 (with 21 OWFs) and 24894.8 km^2 (with 149 OWFs) in the "mid-term" and "long-term", respectively, when all statuses are included (Figure 1). Within the scenario "mid-term", the proportion of areas allocated to OWFs, which are already in a final state of planning ("pre-construction", "fully commissioned", "development zone", or "consent authorized") is minor with 15%. In the scenario "long-term", no final states are included in the dataset. Areas categorized in different statuses of planning are partly overlapping, which results in a likely exaggeration of the final area allocated to OWF, while on the contrary, new OWFs are regularly added to the dataset

The impact of OWFs on ICES-coordinated fisheries surveys in the Baltic

On the first view, the total impact on the acoustic survey (BASS and BIAS) transects and BITS fishing stations seems moderate (<12%, Figure 2). On a smaller scale, e.g. ICES subdivisions and rectangles, however, substantial losses of transects and fishing stations will occur in the long-term (Supplementary Figure S1, Supplementary Tables S1–S3).

The spatial overlap between OWFs and surveys is visualized for the BASS in Figures 3–5, for the BIAS in Supplementary Figures S3–S5, and for the BITS in Supplementary Figures S6–S8. The impact of OWFs in the present situation (scenario "present") is low for the BASS and BITS and there is no overlap between OWFs and the BIAS (Figure 3, Supplementary Figures S2 and S5, Supplementary Tables S1–S3). At present (2022), 3.8 nm (1.3%) of the BASS hydroacoustic transects cannot be sampled anymore compared to the baseline (2020) due to the existing OWF in ICES subdivision (SD) 24, while 2 out of 130 BITS (1.5%) demersal trawl stations now lie in areas with OWFs in SD 24.

In the mid-term scenario (2023–2025), additional losses for BIAS transects and BITS stations are expected, but no further reduction of BASS transects compared to the scenario

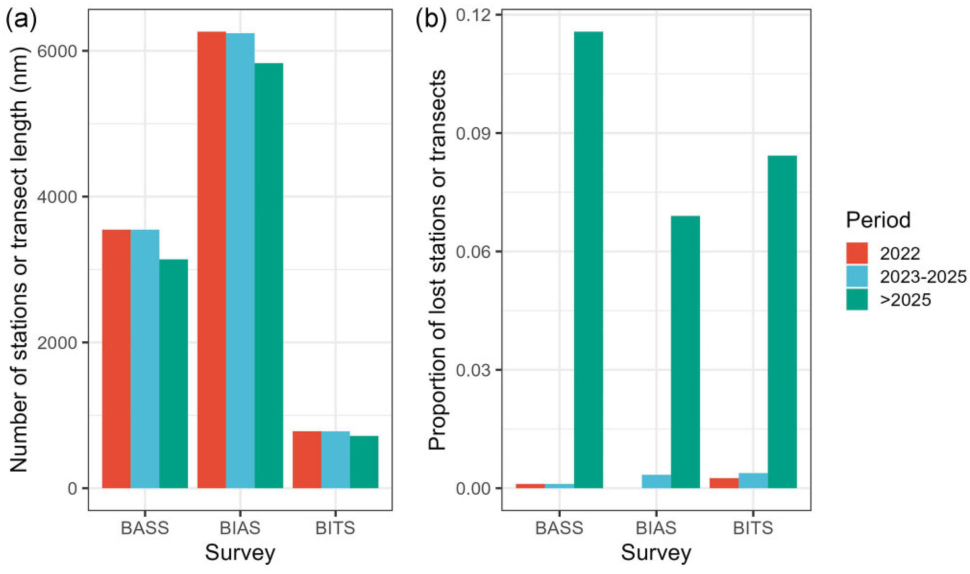

Figure 2. (a) Length of acoustic transects (BASS and BIAS) and the number of fishing stations (BITS) realizable under the scenarios "present" (2022), "mid-term" (2023–2025), and "long-term" (>2025). (B) Proportion of lost stations (BITS) or acoustic transects (BASS and BIAS) under the three scenarios. Refer to Supplementary Figure S1 for a split into subdivisions.

"present" (Figure 4, Supplementary Figures S3 and S6). In comparison with the baseline situation (in 2020), the BIAS would lose 9.3 nm (2.5%), 4.1 nm (0.9%), and 7.9 nm (0.8%) of its transect length in the subdivisions 22, 24, and 30, in the near future (scenario "mid-term"), respectively (Supplementary Tables S1–S2). One station (1.1%) in SD 22 of the BITS is located within an OWF area (Supplementary Table S3).

As expected, the most remote future scenario "long-term" shows substantial losses of both acoustic transects and demersal trawl stations affecting also areas outside the southwestern Baltic Sea. In detail, compared to the baseline in 2020, BASS will lose 11% and BIAS 6.2% of the survey transects, which accounts for 410.8 and 432.1 nm, respectively (Figure 5, Supplementary Figures S4 and S7, Supplementary Tables S1–S2). According to the long-term scenario, up to 8.4% ($n = 66$) of the total number of BITS stations could not be sampled anymore due to OWFs (Figure 2, Supplementary Table S3).

Discussion

A proposed call for action to adapt routine fisheries surveys

The increasing demand for OWFs comes with more and more areas being inaccessible to other activities, including fisheries research. The results clearly show the future loss of acoustic survey transects for pelagic surveys and the loss of fishing stations for demersal trawl surveys, especially in the long-term, with the Baltic Sea as a case study. While there are no drastic losses expected in the nearest few years (2023–2025), an immediate call for action is asked from, among others, ICES survey working groups, already now. Further work is needed to estimate the actual influence on the stock indices and finally the stock assessment. In general, the impact on stock assessment depends on the distribution of the stocks and the location of the individual sections (transects, stations) of the respective surveys. It became clear that if the surveys are not adapted to this change in area availability, substantial percentages of acoustic transect and trawl stations will be lost in the long-term. It needs to be highlighted that the scenario "long-term" involves uncertainty about which percentage of the OWFs are commissioned in the end. This scenario thus might show an exaggerated estimate of areas being allocated to OWFs.

As yet, the most common strategy for adapting hydroacoustic surveys is to bypass OWFs. In demersal trawl surveys, the stations in similar depth strata outside wind park areas are chosen. These simple adaptions, however, might not be possible in all cases in the future and can lead to increased steaming times between stations or transects, which could reduce the total survey coverage. In addition, information about the stock's biomasses within OWFs is lacking and without survey access, these areas can be seen as "black boxes". It is still not fully known what effects (positive as well as negative) the OWFs have on different fish stocks (e.g. Gill *et al.*, 2020; Van Hoey *et al.*, 2021). Hence, a quantitative assessment of resulting changes in the survey design and its consequences for the fish stock indices is difficult to estimate as expert decisions must be made on a case-by-case basis. Spatially reduced sampling effort can result in both increased uncertainty and interannual variation potentially leading to a bias in the stock index calculation when not species-specifically accounted for (Baker *et al.*, 2022; ICES, 2023). Further bias is added when certain habitats become unavailable for surveys. A reduction in survey area might especially affect the estimation of less frequent species and size/age groups as a smaller proportion of the stock is sampled (Nielsen, 2015; Rufener *et al.*, 2021). We highlight the urgent need to collect, analyse, and/or use survey data to further assess how the increase of OWF areas affects the realization of surveys, and how surveys can be adapted to this change. Further, knowledge about how reduced or reallocated sampling effort is influencing the quality of stock indices used in stock assessment and how this translates forward into management recommendations is highly stock and

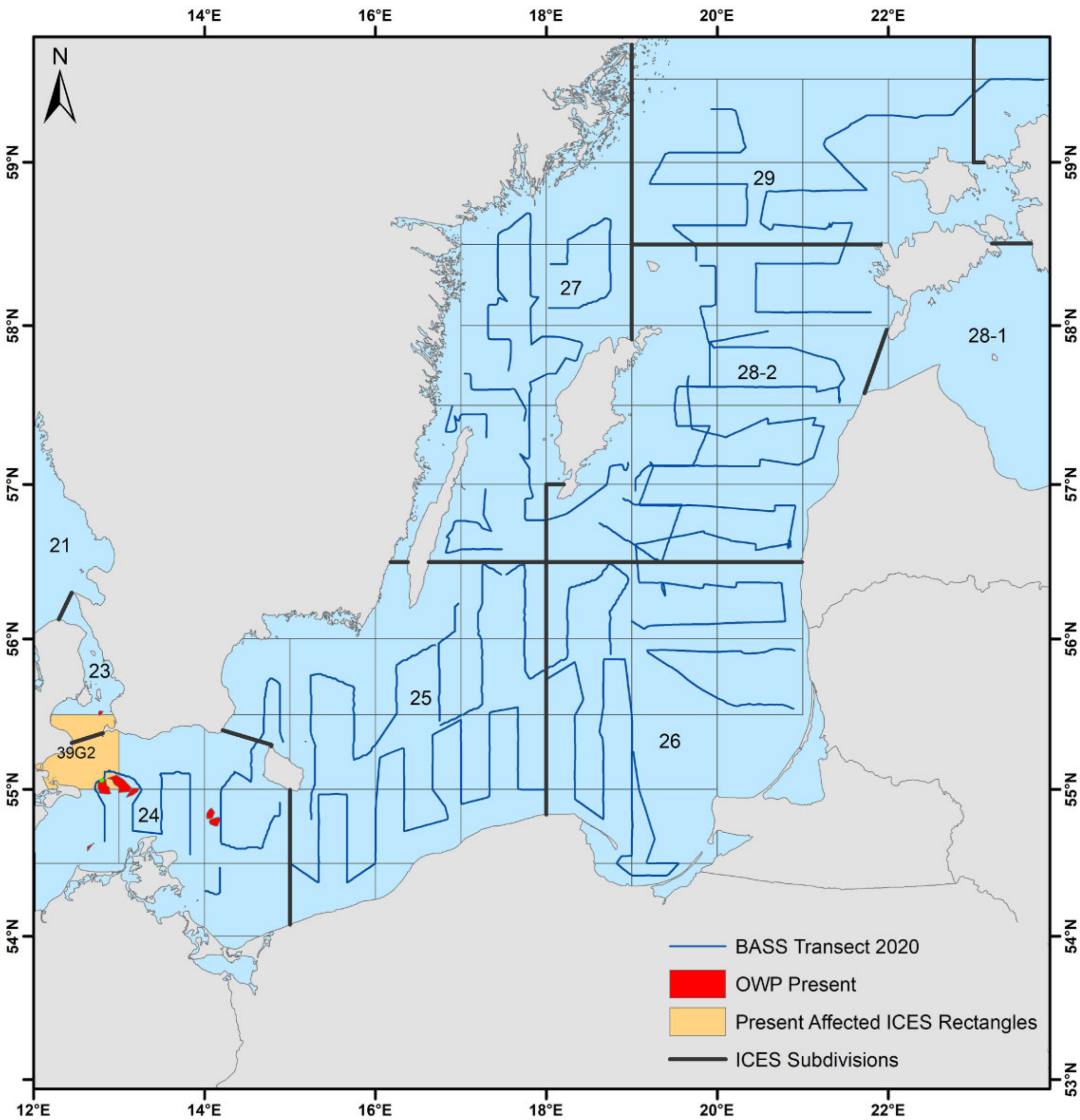

Figure 3. Acoustic transects of the BASS with intersected wind farms areas in the scenario "present" (2022) in the Baltic Sea.

area specific and needs to be tackled in expert groups (i.e. survey and assessment working groups) to provide profound advice.

Practical steps to deal with the lack of survey data

We propose three key steps to address the challenge that an increase of OWF areas and other emerging no-fishing zones poses to fisheries surveys:

(1) Prioritization of high-risk surveys and areas and a qualitative impact assessment

To prioritise the need for action, it is necessary to identify the affected areas that have the potential to impact the stock indices (qualitative impact assessment). These can be areas with a large loss of survey area and/or areas with high fish densities. An initial indication for the Baltic Sea is provided in Figures 3–5 and Supplementary Figures S2–S7, but a detailed analysis is needed to determine whether stations and transects can be relocated to areas not dedicated to OWFs or not fishable for other reasons in compliance with survey requirements, and an analysis of how this affects the stock indices.

(1) Establishment of reference stations and transects

Long, continuous time series are the cornerstone for stock assessment (Gallo *et al.*, 2022). To ensure comparable alternatives for survey areas lost to the presence of OWFs, reference transects and stations should be established and tested well in advance. Additional ship time should therefore be utilized to identify possible alternatives in the areas identified in step 1 above.

(1) Development of alternative surveys methods

Entering OWFs with research vessels, especially those towing nets, is in most cases prohibited in European waters (but see Reubens *et al.*, 2014; Roach *et al.*, 2022). It can be helpful to seek conversations with windfarm operators to get permission to enter OWF areas with research vessels using less in-

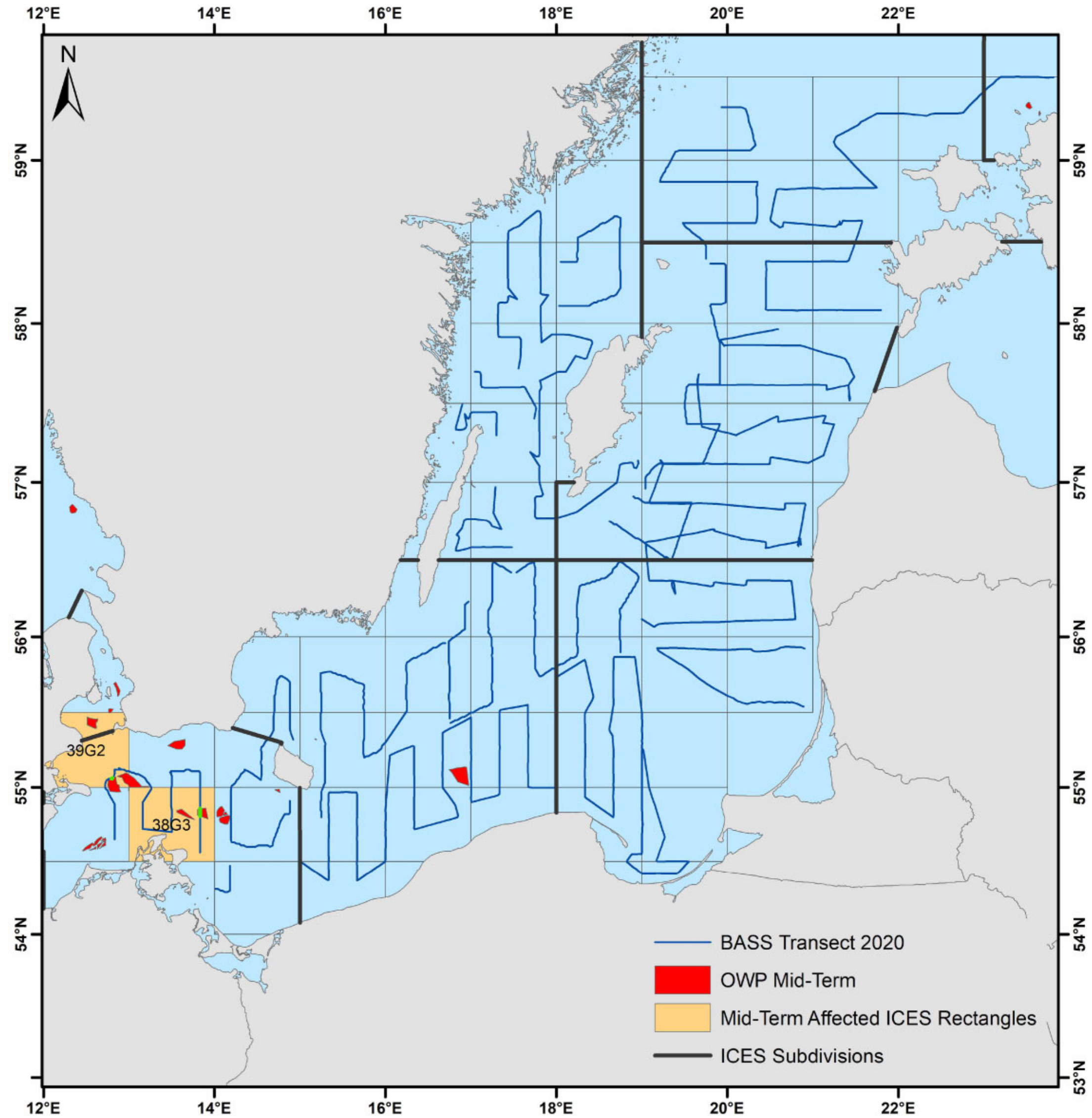

Figure 4. Acoustic transects of the BASS with intersected wind farms areas in the scenario "mid-term" (2023–2025) in the Baltic Sea.

vasive methods. While bottom trawling as conducted during the BITS will likely not be allowed in the future due to the risk of damage to underwater structures such as submarine cables, other less invasive methods are more likely to be allowed. Hydroacoustic surveys, for example, pose little risk when wind turbines are passed by the research vessel at a safe distance. Other, alternative survey methods used in OWFs worldwide include fish traps (Stelzenmüller *et al.*, 2021), angling (Gimpel *et al.*, 2023), video recording (Griffin *et al.*, 2016), and acoustic telemetry (Reubens *et al.*, 2014). A methodological analysis of combining alternative survey methods with current survey protocols is therefore urgently needed. The comparability of alternative survey methods to established and highly standardized methods, however, remains challenging (e.g. Colton and Swearer, 2010; Baker *et al.*, 2016). Extensive gear calibration is required to account for differences in catchability and detectability to avoid biases in abundance estimates (Kimura and Somerton, 2006; Bacheler *et al.*, 2023; ICES, 2023). This process could be supported by model-based indices calculations (see, for example, ICES, 2021b).

Conclusion

Our study provides a first quantitative evaluation of the impact of OWFs on Baltic Sea fisheries surveys at present (2022), in the near future (mid-term; 2023–2025), and far future (long-term; ≥2026). With this paper, we want to raise awareness of the potential loss of important survey areas needed for the sustainable management of fish stocks in the Baltic Sea, as well as worldwide. While currently the presence of individual OWFs seems manageable, our results show, even without qualitative impact assessment, that action is needed now to adapt for a development picking up speed after 2025, according to announcements by governments in different countries. We propose three practical steps to minimize the impact of increasing OWF areas on fisheries surveys and thus on stock indices. Given the need for fishery-independent survey data as an important input for stock assessment for a large proportion of commercially harvested fish stocks, this study can also serve to highlight the importance of including fisheries research and

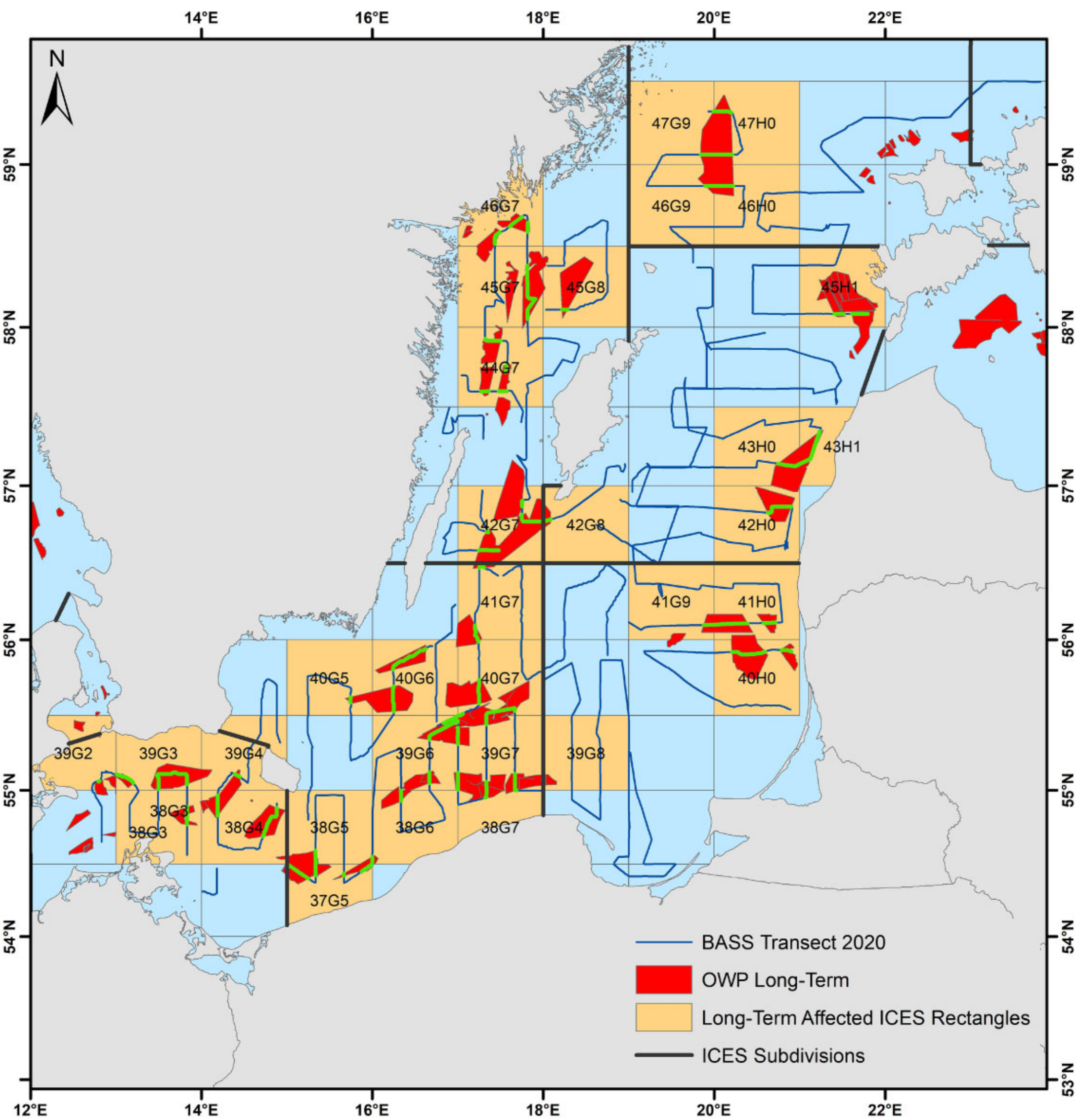

Figure 5. Acoustic transects of the BASS with intersected wind farms areas in the scenario "long-term" (>2025) in the Baltic Sea.

management interests in environmental impact assessments in areas attractive for OWF use.

Acknowledgements

We want to thank colleagues at the ICES Annual Science Conference 2022 for a fruitful discussion within the theme session on "Methodologies to assess the impact of offshore wind development on fishery data collections". We would like to thank the editor and reviewers of this manuscript, who gave valuable and insightful feedback.

Author contributions

SH: Conceptualization, Methodology, Formal analysis, Visualization, Writing—original draft, Writing—review and editing; CD: Writing—review and editing; OK: Writing—review and editing; NP: Data curation, Visualization; ES: Writing—review and editing; VS: Data curation, Writing—review and editing; AV: Methodology, Formal analysis, Writing—review and editing; DO: Conceptualization, Writing—original draft, Writing—review and editing.

Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript. A figure about the length of acoustic transects (Baltic Acoustic Spring Survey; BASS and Baltic International Acoustic Survey; BIAS) and number of stations (Baltic International Trawl Survey; BITS) realizable under the scenarios "present" (2022), "mid-term" (2023–2025), and "long-term" (>2025) split into subdivisions and the proportion of lost stations (BITS) and acoustic transects (BASS and BIAS) under the three scenarios. Maps visualizing the overlap between offshore windfarms and the hydroacoustic survey "BIAS" and the demersal trawl survey "BITS" in the scenarios "present" (2022), "mid-term" (2023–2025), and "long-term" (>2025; Supplementary Figures S2–S7). Three overview tables of (i) the Baltic Acoustic Spring Survey (BASS), (ii) the Baltic International Autumn Survey (BIAS), and (iii) the Baltic

International Trawl Survey (BITS) and its spatial conflict with offshore windfarms in the scenarios “present” (2022), “mid-term” (2023–2025), and “long-term” (>2025) in the Baltic Sea.

Conflict of interest: The authors have no conflicts of interest to declare.

Funding

Parts of the manuscript were funded by the German Federal Ministry of Education and Research under grant number 03F0911F.

Data availability

Demersal and acoustic survey data are available at https://datras.ices.dk and https://www.ices.dk/data/data-portals/Pages/acoustic.aspx, respectively. Information on offshore windfarm areas were purchased from 4C Offshore Ltd and cannot be shared publicly.

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Handling editor: David Secor