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Status and perspectives for pikeperch (*Sander lucioperca*) stocks in the Baltic Sea region and central Europe

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Abstract

Pikeperch (*Sander lucioperca*) is a European fresh and brackish water piscivorous fish, important as a key predator and a valuable fisheries species. Despite concerns that some stocks are depleting due to overfishing and environmental changes, stock assessments are implemented sporadically. We provide an overview of data collection and population assessments currently used for nine pikeperch stocks across six European countries and apply a unified assessment framework (Bayesian surplus production models) to evaluate population status and trends. Our results show that three stocks, including two in the Baltic Sea, are strongly depleted, with estimated biomasses considerably lower than the biomass at maximum sustainable yield (B_{MSY}). Other stocks are close to their estimated B_{MSY}. Further, recent population trends suggest that only one stock (Kvädöfjärden) is increasing, whereas three (Curonian Lagoon, Lipno, Galtfjärden) are rapidly declining. In most cases the stocks with a favourable status or signs of recovery were also those for which strong management strategies have been implemented. Importantly, although most stocks are strongly targeted by recreational fishing, estimates of recreational catch are highly uncertain. We highlight an urgent need to improve pikeperch scientific monitoring and assessment of recreational catches.

Keywords: surplus production models, data limited stocks, inland fisheries, coastal fisheries, recreational fishing

1. Introduction

Regular population assessments are more likely to lead to sustainable fisheries (Melnychuk *et al.*, 2021), yet, a majority of the world's fish populations remain unassessed, especially in coastal and inland regions. Pikeperch (*Sander lucioperca)* is a key predatory fish species in European coastal, brackish, and freshwater ecosystems and is highly valued by both commercial and recreational fishers (Arlinghaus and Mehner, 2004). Being one of the largest predators, pikeperch also plays important ecological and regulatory roles (Ranåker *et al.*, 2014). However, many pikeperch stocks are depleted (Mustamäki *et al.*, 2014; FAO, 2022) or their status is uncertain. Globally, reported commercial pikeperch catches declined from 50 thousand tons in 1950 to 14.6 thousand in 2009, although they increased to 26 thousand tons by 2020 (Colchen *et al.*, 2020; FAO, 2022). These statistics may ignore inland fisheries and do not include recreational catches, which for many pikeperch populations likely exceed commercial catches (Heikinheimo *et al.*, 2014; Dainys *et al.*, 2022a, b). Most countries do not collect regular data on recreational catches and their impacts, and given recent advances in recreational fishing technology, there is an urgent need to review and better monitor pikeperch population status.

Despite its importance, current data collection and assessment of European pikeperch populations remains limited. Although some stocks in Finland, Estonia and Sweden have been assessed with age-based virtual population analyses (Eero, 2004; Härkönen *et al*., 2023; Olin *et al*., 2023), assessments of most other stocks are based on mean size trends, reported commercial or recreational catches, or are not undertaken at all (see Table S1). Currently, population analyses paint a diverse picture in the Baltic Sea region and central European waters. In Finland's inland and coastal waters, growing commercial and recreational catches suggest improved population status (LUKE, 2022). In contrast, fishery independent monitoring of Swedish coastal pikeperch populations in the northwest region of the Baltic Sea suggests large declines in abundance since 1995 (Mustamäki *et al.*, 2014). A similar decrease in pikeperch abundance is seen for the Pärnu Bay in Estonia (Eschbaum *et al.*, 2021) and the Curonian Lagoon in Lithuania (Andrašūnas *et al.*, 2022), and scientific surveys show that many other populations in the Baltic region have been declining (Bergström *et al.*, 2016). For freshwater populations, declining status of pikeperch stocks led to the complete closure of commercial fishing in Kaunas Water Reservoir in Lithuania (Kaunas) in 2013, but large recreational catches likely precluded the expected population recovery (Dainys *et al.*, 2022a). Similarly, recreational catches are also likely to be the main driver for the population declines in Lipno Reservoir, Czech Republic (Lipno) (de Moraes *et al.*, 2023).

Lack of uniform and regular assessments of pikeperch populations is likely to impede appropriate management. Regular assessments are particularly important considering rapidly changing environmental conditions and the increasing popularity and efficiency of recreational fishing. For example, climate warming and eutrophication are likely to be benefiting some populations, given that pikeperch thrives in warm, turbid, well-oxygenated and productive ecosystems (Veneranta *et al*., 2011; Müller-Karulis *et al*., 2013). Similarly, rapid improvement in recreational fishing technology and increasing popularity of catch and release fishing are also likely to be altering mortality and abundance of many populations, although the directions of these changes remain unknown. To address these challenges, this study aims to bring together diverse data sources from a range of European marine and freshwater pikeperch populations and use these data in a standardised manner to conduct a unified analyses of population status. More specifically our aims are: 1) to briefly review current pikeperch stock assessment approaches and management policies across six European countries, 2) apply a unified analysis using Bayesian surplus production modelling (Winker *et al.*, 2018) across all populations using statistically standardised catch per unit effort (CPUE) time series, and 3) provide recommendations for improving data collections and monitoring of pikeperch populations.

2. Data and methods

2.1. Study areas and data

We analysed nine pikeperch populations from six northern and central European countries (Finland, Sweden, Estonia, Lithuania, Czech Republic and Austria), representing a cross section of marine coastal and inland water bodies with different management strategies (Fig. 1, Table S2). Data used in this study were contributed by the relevant scientists from each country and included >20 years of commercial effort and catches, recreational catches (where available) as well as scientific surveys (Table S3, S4). Further details about the data for each stock are provided in the Supplementary material. During the process of data collection, we also asked experts from each country (i.e., authors of this study) to evaluate the quality of recreational, commercial and scientific survey data on a 1 (unreliable) to 5 (highly reliable) scale (Table S4). Full details on the ranking criteria and data quality assessment results are shown in the Supplementary material.

2.2. CPUE estimation and standardisation

Depending on data availability, CPUE time series for surplus production models (SPM) were estimated from scientific surveys, commercial or recreational catch and effort data (Table S4). The use of CPUE as an index of relative abundance requires the removal of the effects of variation due to changes in factors other than stock biomass (such as season, location etc.). We standardized CPUE using generalised linear models with a Tweedie distribution (Shono, 2008), as implemented in the R (R Core Team, 2023) packages ‘statmod’ (v. 1.4.33) and ‘tweedie’ (v. 2.3.3). For full details of model selection see Supplementary material, Table S5.

2.3. Surplus production models

We applied the open-source Bayesian state-space surplus production model (SPM) framework JABBA (Winker *et al.*, 2018). The state-space framework enables incorporation of both observational and process errors, and the Bayesian approach allows quantifying uncertainty in the parameter estimates. A critical assumption in SPMs is the percentage of the stock carrying capacity, which gives the highest production and therefore maximum sustainable biomass (B_{MSY}). This can be assumed at 37% if models apply the Fox production curve, 50% for Schaefer’s production curve, or can be set at a higher level with a generalized Pella-Tomlinson (1969) production curve. We chose the Pella-Tomlinson production function and assumed that B_{MSY} occurs at 65% of the stock’s carrying capacity. It is the most conservative approach, which is likely to be more accurate for pikeperch stocks, given the evidence that size structure and stock-specific recruitment conditions can exert large impact on population viability and therefore on MSY (Maunder, 2003; Vainikka and Hyvärinen, 2012; Vainikka *et al.,* 2017). A more conservative and precautionary approach is also warranted given the largely unknown but potentially substantial recreational fishing pressure (e.g., see Embke *et al.,* 2019 for a demonstration of large recreational fishing impact on the North American stocks of a closely related species), as well as lessons learned from overly optimistic model forecasts for other fisheries stocks (Walters and Maguire, 1996). A more commonly used Schaefer function was also applied, with model outcomes provided in the Supplementary material. JABBA requires prior information on the resilience parameter *r* (intrinsic rate of population increase), carrying capacity *K* and the relative initial biomass at the beginning of the time series. Priors for *K* and initial biomass were stock specific, whereas *r* priors were identical for all stocks and were based on classifying pikeperch as a low resilience species (Froese *et al*., 2017) (see Supplementary material for further details). To evaluate the model's goodness-of-fit, we used the standard deviation of the normalized residuals (SDNR) and a runs test (Francis, 2011), which assess the randomness and the magnitude of CPUE time series residuals compared to model predictions.

2.4. Mean size estimation

Given that SPMs do not consider population size structure, we have also explored trends in population mean size across the studied periods. Individual size data were collected either from commercial catches (i.e., all fish above the minimum size limit) or scientific monitoring (the full range of mesh sizes), so that although mean sizes cannot be compared across different sampling methods, they are nevertheless useful as an indication of trends in population body size. To account for variability across sampling seasons, mesh sizes and sites within a population, yearly changes in mean length were estimated using linear models, similar to the CPUE analyses above. Fixed effects, as well as initial and final models varied for each stock, depending on the sampling parameters (Table S5).

3. Results

3.1. Data collection and quality and current stock management

Based on expert judgement, reporting of commercial catch data was of relatively high quality (data quality values typically ranging at 4-5, Table S4). International cross-jurisdictionally managed Curonian Lagoon and Lake Peipsi had the lowest commercial catch data scores. Commercial effort data were considered of high quality only for the Finnish Archipelago and Lake Oulujärvi. In other places, commercial effort is collected as the total allowable, rather than the actual effort (e.g., number of fishery permits in Lake Constance); is available only on a much larger spatial scale (entire Swedish coast, rather than specific stocks); or reporting requirements have changed through time (Curonian Lagoon) making comparisons unfeasible. Fishery independent scientific surveys are conducted annually in five out of nine stocks with consistent methodology and provide high quality data (scores of 5) (Table S4). For the Finnish Archipelago and Lake Oulujärvi no fishery independent scientific surveys are taking place.

The main gaps in data availability were in recreational catch and effort. Only five stocks had some estimates of recreational catches, and only one of them (Lipno) was considered of high quality and was based on mandatory catch reports. For other stocks, recreational catch estimates were either limited to short time periods (Kaunas), were based on questionnaires and therefore potentially biased (Finland) or conducted only every few years (e.g., every 5th year in Lake Oulujärvi). In the Baltic Sea stocks (Curonian Lagoon, Galtfjärden, Kvädöfjärden) no assessment of recreational catch was available, although rough estimates along the Swedish coast suggest that recreational catches could exceed the commercial catch (Sundelöf *et al.,* 2022).

In most European pikeperch stocks studied here, current population assessment methods rely on trends in commercial catches, commercial and scientific CPUE or body size statistics (Table S1). Only two populations (Finnish Archipelago and Lake Oulujärvi) have been assessed with a more complex virtual population analysis (Table S1).

3.2. Management policies

In most cases, management policies used for commercial pikeperch harvest are based on either total allowable catch (TAC) (two out of seven commercially harvested populations) or total allowable effort (TAE, setting number and types of gears) for the remaining populations. All populations have size restrictions on harvest, such as minimum mesh size and a minimum landing size, typically set at about 45 cm total length (Table S2). In Curonian Lagoon, TAC for the commercial fishery is implemented on the Russian side, while in the Lithuanian side, management since 2013 applies TAE restrictions only. Seasonal and spatial closures for commercial fisheries apply only in the Curonian Lagoon. For two inland populations (Kaunas and Lipno) commercial fishing is currently banned (since 2013 and 1976 respectively). Recreational fishery management typically involves daily bag limits, minimum landing size (ranging from 40 to 46 cm) and in some cases restrictions on lures (only in Lipno) or seasonal closures lasting from two to six months (Table S2). Total recreational catch is not restricted in any populations. Since 2009, permanent spatial closures have been implemented in Lipno and now encompass 6% of the total reservoir area, being the only pikeperch population with permanent spatial closures.

3.3. Pikeperch stock status

Both Pella- Tomlinson and Schaefer production models produced similar population trends for all stocks in this study. Models using the Pella-Tomlinson production function showed that during 2019–2022 three out of nine studied stocks (Curonian Lagoon, Lipno and Galtfjärden) were confidently in depleted state with the estimated stock biomass and its uncertainty ranges below the B_{MSY} (Fig. 2, for Kobe plots see Fig. S1) and same results were obtained with the Schaefer production model (Fig. S2). Trends in mean length of pikeperch also showed declining trends in the Curonian Lagoon and Lipno but were relatively stable size for Galtfjärden. None of the stocks were confidently above B_{MSY} (Figs 1, 2) using the Pella-Tomlinson model, but four stocks were above B_{MSY} when the Schaefer model was applied. Regardless of the model, four stocks (Kvädöfjärden, Lake Oulujärvi, Lake Peipsi, and Upper Lake Constance) showed relatively good status with biomass levels close to the estimated B_{MSY} and mean sizes for the first three populations also remaining stable. Finally, for Kaunas and Finnish Archipelago the estimated biomasses were slightly lower B_{MSY}, but there was a small increase in mean size in Kaunas and a stable mean size in commercial catches in Finnish Archipelago. In all six populations (Kvädöfjärden, Lake Oulujärvi, Lake Peipsi, Upper Lake Constance, Kaunas and Lipno) the uncertainty ranges overlapped with B_{MSY} values.

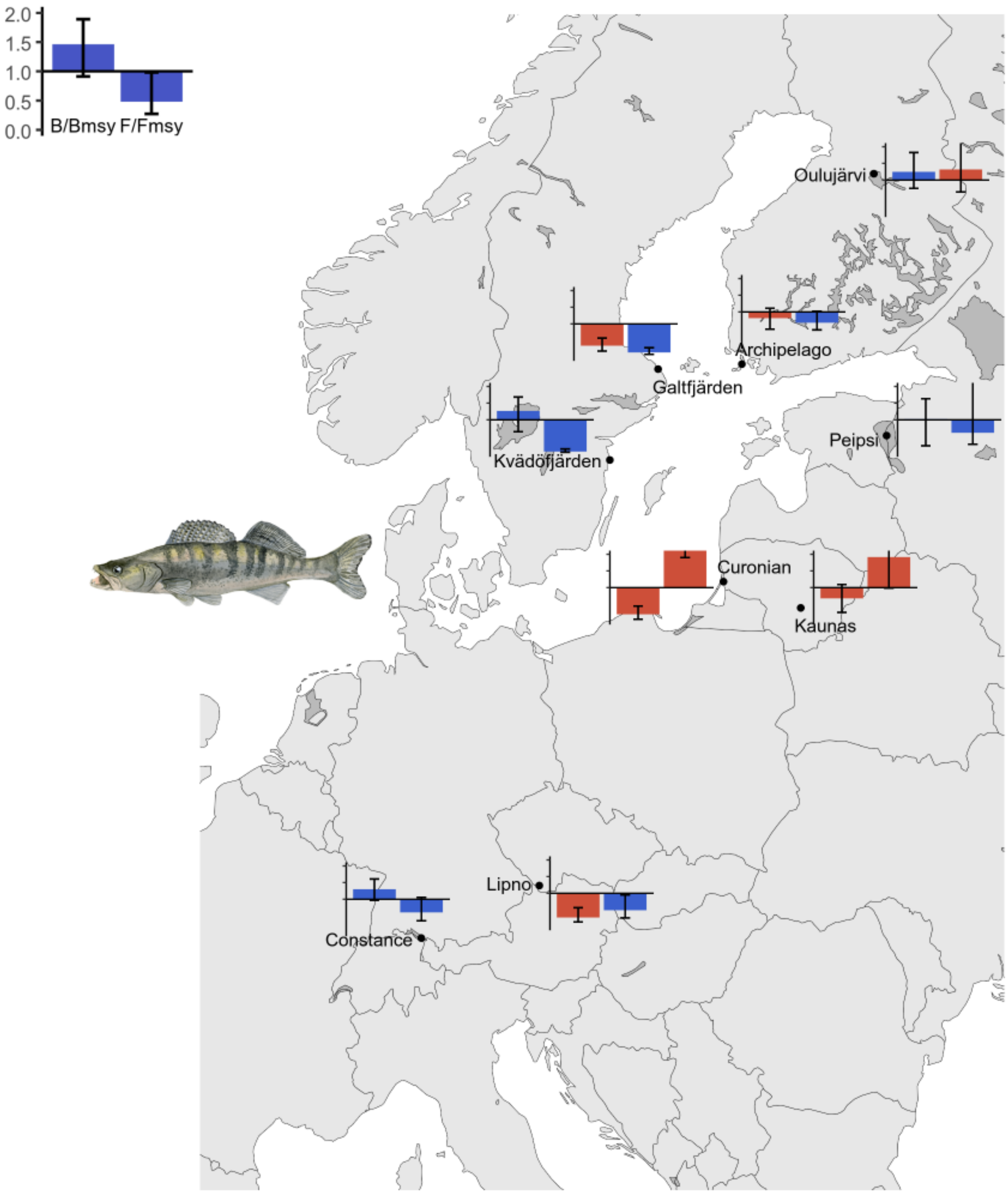

Fig. 1. Status of pikeperch stocks (last year in the time series, 2019 to 2022) in the European populations studied. The first bar illustrates the ratio of current biomass (B) versus biomass required for maximum sustainable yield (B_{MSY}), where values in blue (>1) indicate a good status and values in red (<1) show bad status. The second bar shows the current fishing mortality (F) versus mortality leading to a maximum sustainable yield (F_{MSY}) and values <1 indicate good status. Error bars show uncertainty intervals from the surplus production models (see Fig. 2).

When looking at population trends, the status of four pikeperch stocks has improved over the last decades. Specifically, Lake Peipsi pikeperch biomass was low in the 1960–1970s, but since 1990s–2000s the stock is in a good state and still improving (Fig. 2). In Lake Oulujärvi pikeperch population collapsed in the 1960–1970s, and despite stocking since 1985, biomass remained very low until the onset of natural reproduction in 1998. Currently the stock seems to fluctuate around B_{MSY}. The Kvädöfjärden stock along the Swedish coast also showed signs of recovery in biomass, yet mean fish sizes have been decreasing over the last two decades (Fig. 2). The Finnish Archipelago population biomass declined in 2000s but appears to have stabilised since 2010.

In contrast, four other stocks - Curonian Lagoon and Galtfjärden in the Baltic Sea, as well as Kaunas and Lipno – showed a declining biomass over recent decades, with the lowest levels in the Curonian Lagoon and Galtfjärden. Despite declining overall biomass, the mean size of pikeperch in Kaunas has been increasing, whereas in Lipno neither biomass nor mean size has shown any signs of recovery. Finally, the population status in Lake Constance appeared to be good, with biomass above B_{MSY} and relatively low fishing mortality. However, this result is uncertain, because the time series of CPUE and catch data didn't include sufficient contrast in population abundance to estimate population parameters and available data quality was relatively low; as a result, the overall model fit is relatively poor.

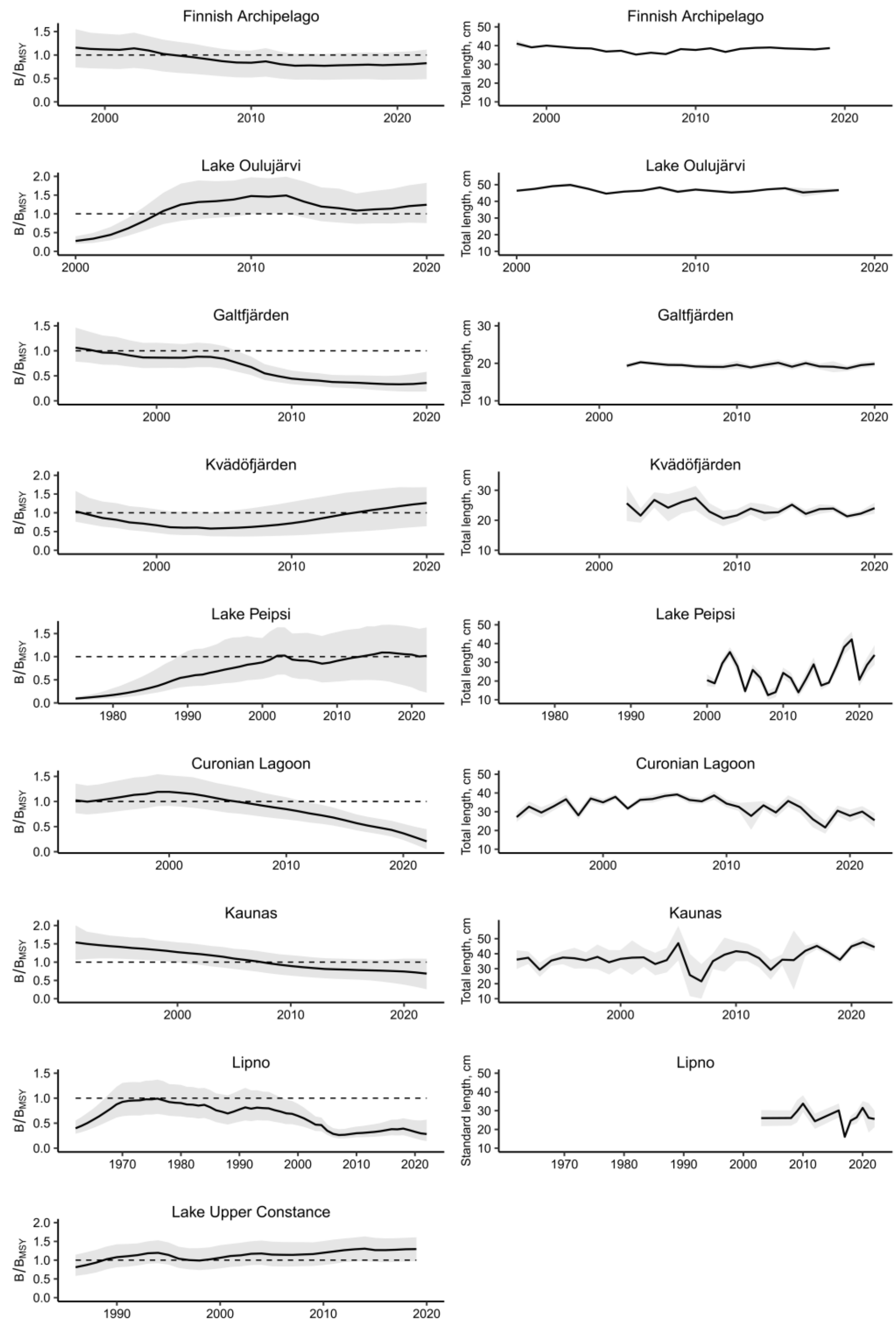

Fig. 2. On the left: Relative pikeperch biomass of the nine stocks assessed. The y axis indicates the biomass relative to the biomass at maximum sustainable yield (B_{MSY}). The grey area and the thick central line show the 95% and 50% posterior probabilities. Note the different time series for each stock. On the right: Trends in mean length using data from scientific surveys (Lake Peipsi, Galtfjärden, Kvädofjärden, Curonian Lagoon, Kaunas, Lipno) or commercial catches (Finnish Archipelago, Lake Oulujärvi).

4. Discussion

The pikeperch stocks analysed in this study provide a good representation of northern, eastern and central European populations across different countries, habitats, management and monitoring practices and fishing impacts. Some populations are mostly exploited by commercial fisheries (in the Baltic Sea) while others are fished only recreationally (Kaunas and Lipno). Overall, our results show a mixed picture of both declining and improving trends in different areas, with about half of the population being close to their maximum sustainable yield biomass levels and the remaining half being moderately or strongly depleted. However, none of the stocks were confidently above B_{MSY}, while three stocks were confidently below, indicating the need for better management plan for commercially and recreationally intensively harvested pikeperch in Europe.

4.1. Trends and status of Baltic Sea populations

Our study suggests that the most concerning situation occurs in two coastal stocks in the Baltic Sea - Curonian Lagoon and Galtfjärden, the latter finding also supported by decreasing pikeperch age in commercial catches (Sundelöf *et al.,* 2022). In the coastal areas of the Baltic Sea pikeperch traditionally supported important commercial fisheries (Fig. S3), but in recent years its significance has decreased, and sustainability of these fisheries have been questioned (Eero, 2004; Eesti Mereinstituut, 2016). Many fisheries harvest a large proportion of the pikeperch stock soon after or even before reaching maturity, and despite minimum size limits, discard mortality from commercial fisheries can be high (Ložys *et al*., 2022). Recreational fishing, although often not assessed, is also likely to be intense (Sundelöf *et al*., 2022), and some stocks may also be facing high predation pressure from seals and cormorants (Mustamäki *et al*., 2014). One of the most depleted and still declining stock is in the Curonian Lagoon, even though commercial catches over the last decade have remained surprisingly stable (Fig. S3; Andrašūnas *et al*., 2022). This stability is likely caused by increases in fisheries efficiency through recent adoption of modified fyke nets, which unfortunately also leads to high incidental mortality of undersized fish (Ložys *et al.,* 2022). Further, although not included in this study due to low data availability and quality, the status of the Pärnu Bay (Estonia) pikeperch stock is also considered poor (Eschbaum *et al.,* 2021). This population once yielded substantial commercial catches (800 tons in the 1930s, 150-300 tons in the 1990s), but has collapsed in the 2000s and has since remained in a poor state.

In contrast to the poor status of Galtfjärden stock along the Swedish coast, the biomass of a nearby Kvädöfjärden (Fig. 2) stock is increasing, and this is also supported by other ecological time series data (HELCOM, 2023). However, Kvädöfjärden pikeperch body sizes are decreasing and the reasons for biomass recovery remain unclear. One Baltic Sea area where status of pikeperch stocks appears to be relatively stable and likely improving during recent years is in the Finnish Archipelago. This might be thanks to the increased minimum landing sizes (from 37 cm to 40 or 42 cm TL in 2019 depending on the area, Vainikka *et al.* 2017; Olin and Raitaniemi, 2021) and reductions in commercial fishing effort since 2003 (LUKE, 2022). Increasing water temperature (Viitasalo and Bonsdorff, 2022) and eutrophication may also be improving pikeperch reproduction success and individual growth rates, given that these populations are close to their northern distribution limit. Nevertheless, the recovery of pikeperch in the Finnish Archipelago remains slow, possibly due to bycatch mortality of undersized pikeperch (Olin and Raitaniemi, 2021), cormorant and seal predation (Heikinheimo *et al.,* 2015; but see Olin *et* *al*., 2023) or recreational fishing. Angling effort in the Finnish Archipelago is high and recreational catches in Finland generally exceed the commercial catch (LUKE, 2022). In fact, most coastal Baltic Sea stocks attract intensive recreational fishing, although the effort and catches remain highly uncertain. For example, in 2014 recreational catches along the coasts of Sweden were estimated to be in the range of 9 to 64 tonnes compared to just under 14 tonnes in the commercial fishery (Sundelöf *et al*., 2022). Although uncertain, estimates for recreational catches in the Pärnu Bay and Pärnu river in 2022 were around 26 tonnes, compared to 22 tonnes for the commercial fishery (Kantar, 2023). Unfortunately, for the Curonian Lagoon, even an approximate estimate is not available.

4.2. Origins and status of freshwater populations

The natural distribution of pikeperch in Europe is largely confined to coastal and brackish habitats and river deltas. Many freshwater populations in Finland, Czech Republic, Lithuania and Austria have been established by stocking, although many now also have natural recruitment (Table S2). In Lipno and Kaunas pikeperch occurred naturally before the respective damming of the Vltava and Nemunas rivers (Vostradovsky and Tichy, 1999), but populations were further augmented by stocking. Several important native freshwater pikeperch stocks in Finland, including the Lake Oulujärvi population, collapsed during the 1960s and early 1970s potentially due to overfishing and low temperatures at the time (Colby and Lehtonen, 1994), and have been restored through reintroductions and subsequent stocking. Currently, pikeperch stock status in Oulujärvi is reasonably good, and this is also supported by an age-structured model applied for this stock (Harkonen *et al*., 2023). In large lakes, such as Oulujärvi in Finland (ca 900 km^2) or Lake Peipsi in Estonia (ca 3550 km^2) commercial fishing seems to be considerably more important than recreational catches (Kantar, 2023) and hence harvest controls may be easier to impose. Both Oulujärvi and Peipsi stocks are in an overall good status, with population biomasses close the B_{MSY} limits and mean sizes of fish remaining stable or increasing.

The situation is different in Lipno and Kaunas reservoirs, which are among the most popular national angling destinations, are considerably smaller (ca 50-60 km^2) and therefore easily accessible by anglers. Despite commercial fishing bans in both reservoirs, pikeperch stocks there remain below B_{MSY} limits. There is evidence for some recovery in Kaunas with mean fish body sizes increasing slightly, but such recovery does not seem to occur in Lipno. This lack of recovery is perhaps not surprising, given a rapid increase in recreational angling efficiency (Cooke *et al.*, 2021) and the fact that the relative role of commercial catches might have been small anyway. For example, assessment of recreational effort and catches showed that recreational catches in Kaunas reservoir exceed former commercial catches several fold (Dainys *et al*., 2022a, b). Recreational fishing also creates an indirect negative effect on pikeperch populations, by increasing competition between pikeperch juveniles and cyprinid fish species. As proportions of predatory fish in populations decline due to intensive harvesting (Myers *et al.,* 2003; Fogliarini *et al.,* 2021), cyprinids, such as bream and roach, often become the dominant species in freshwater and brackish coastal systems (Dainys *et al.,* 2022a). Both young pikeperch and cyprinids compete for food in their early life, yet under low food conditions cyprinids can switch to feeding on detritus and periphyton (Richeux *et al.,* 1992), whereas pikeperch depend entirely on animal food.
Despite the importance of recreational catches on freshwater pikeperch populations, regular recreational fishing assessments are largely absent in most countries, except for the Czech Republic, where recreational catch reporting has been mandatory for decades. Recreational angling management remains largely restricted to

minimum size and daily bag limits, without attempting to limit the overall catch. A noticeable exception is Lipno, where a permanent spatial closure has been implemented since 2009, comprising 6% of the total reservoir area. Pikeperch was found to be more abundant and larger sized in the protected areas (de Moraes *et al.,* 2023). The main management measure incurring significant expenditure applied in most countries remains regular restocking of pikeperch. This restocking occurs despite consistent evidence that it may contribute little to the replenishment of naturally reproducing populations and may have negative impacts due to introduction of diseases, parasites and mixing of genetic lineages (Radinger *et al.*, 2023). For example, practically all pikeperch stocking programmes in Finland have relied upon only a few source stocks, all of them of southern origin (Salminen *et al.,* 2012). The contemporary pikeperch stock in Lake Oulujärvi (64°N) stems from the Lake Vanajavesi (61°N) stock (Salminen *et al.,* 2012) and despite effective natural reproduction in Lake Oulujärvi since 1998 (Vainikka and Hyvärinen, 2012), the population is still annually enhanced by releasing about 300,000 young-of-the-year fish. Regular stocking is still applied in Lipno, despite evidence that only about 20% of adult fish derive from stocking (Souza *et al.*, unpublished data). A similar situation occurs in Lake Constance, where pikeperch were originally introduced in the late 1800s and are stocked almost annually, despite studies showing that stocking has limited benefits (Löffler, 1998).

4.3. Future research needs and perspectives

Given that the majority of freshwater and coastal fish populations do not feature regular ageing data and therefore cannot be assessed using age-structured stock assessment models (Costello *et al.,* 2012), data-limited methods such as SPM can provide an important alternative approach. In our study, results of SPM for Lake Oulujärvi concurred with outputs from an age-structured model for the same population (Harkonen *et al*., 2023). Despite their simplicity, SPMs are widely used for stock assessment (Wang *et al.,* 2014; Cousido-Rocha *et al.,* 2022) and are among the simplest of full stock assessment tools which can inform managers about reference points, stock size and recommended harvest rates (Ludwig and Walters, 1985, 1989). However, SPMs make a key assumption that population abundance is driven by catches, population regeneration or growth rate (r) and carrying capacity (K). This means that all aspects of production are pooled into one production function ignoring age, size, and sex structure. Environmental variation is also either ignored or incorporated into process uncertainty, as is the case with JABBA applied here. SPMs perform best when time series of catch and population abundance data have sufficient contrast to estimate population growth parameters. If data lack contrast, this may suggest that catches have always been managed at sustainable levels or that the stock may be more influenced by factors other than catch e.g., environmental variation (Haddon, 2020). This is likely to be the case for Upper Lake Constance, where pikeperch is not an important target species, and the available data provide little information regarding stock status.

An important next step to improve assessments and management of pikeperch populations is regular collection of fish body size data. Another essential step would be to focus on assessing and managing recreational catches. Despite growing global recognition that recreational fishing may have large impacts on populations, most countries do not require anglers to report their catches (Cooke *et al.*, 2015, Potts *et al.*, 2020). Although proportions of fish being released during angling trips may be increasing, catch and release angling still contributes to population mortality (Arlinghaus *et al.,* 2002; Sass and Shaw, 2020). Maximum size limits to create harvest slots are only implemented for coastal fish populations in Sweden, despite evidence that larger and older females of many fish species have better spawning success than younger ones (Berkeley *et al.,* 2004; Olin *et al.,* 2012). Permanent spatial closures that ban all fishing are still very rare in the countries included in this study and are not imminent, despite their demonstrated importance for population resilience and protection of important species traits, often selectively removed by anglers (de Moraes *et al*., 2023). Such strategically located spatial closures could help build resilience against impacts of climate change and environmental fluctuations (Olin and Raitaniemi, 2021). They can also protect a fraction of a population from human induced evolutionary trends, which could have large impacts on pikeperch stock dynamics (Vainikka and Hyvärinen, 2012; Vainikka *et al*., 2017).

Climate warming and eutrophication of coastal and inland waters are also likely to have some positive effects on pikeperch stocks. In general, pikeperch are believed to benefit from eutrophication and rising water temperatures, because turbid, warm water positively influences pikeperch spawning success and increases somatic growth rates (Pekcan-Hekim *et al.,* 2011; Veneranta *et al.,* 2011). This is especially true for populations in Northern Europe, where pikeperch recruitment and growth are correlated with summer temperatures (Tesfaye *et al.*, 2023). With rapid climate and other environmental changes coupled with increasing popularity of recreational fishing, it is important that pikeperch populations are regularly monitored with consistent and comparable scientific methods and that the scientific community further improves its data sharing and collaboration on population status assessments.

CRediT authorship contribution statement

AA, HG, EJ: Conceptualization, methodology. EJ, AA, AŠ: Formal analysis. AA: Supervision. EJ, LL, LSH, PH, RN, JK: Data curation. AA, LL: Funding acquisition. EJ, AA: Visualization. EJ, HG, AA, MO, JTD, RN: Writing – original draft. All: Investigation, Writing – review & editing.

Data availability

Raw data from scientific, commercial and recreational catches and effort can be requested from respective institutions and authors. Standardised CPUE effort and catch times series used in this analysis, together with R codes are available on https://github.com/eglejak/pikeperchEurope and archived on Zenodo (DOI: 10.5281/zenodo.8402736)

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