Fisheries Research 268 (2023) 106829

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

# Catches, bycatches and stock indicators of fisheries targeting cyprinids along the Swedish Baltic Sea coast

Örjan Östman [a,*], Göran Sundblad [b], Peter Ljungberg [a], Sandra Levin [a,c], Martina Blass [a], Marju Kaljuste [a], Iris Dahlin [a,d], Rebecka Svensson [a], Jens Olsson [a]

[a] *Uppsala County Board, 751 86 Uppsala, Sweden*
[b] *Swedish University of Agricultural Sciences, Dept. Crop Production Ecology, Ulls väg 16, 756 51 Uppsala, Sweden*
[c] *Swedish University of Agricultural Sciences, Dept. Aquatic Resources, Skolgatan 6, 742 42 Öregrund, Sweden*
[d] *Swedish University of Agricultural Sciences, Dept. Aquatic Resources, Stångholmsvägen 2, 178 93 Drottningholm, Sweden*

ARTICLE INFO

*Keywords:*
Abundance indicator
By-catch
Length-based indicators
Seafood
Sustainable harvest

ABSTRACT

Decreasing abundance of many traditionally exploited fish stocks in the Baltic Sea force small-scale fisheries to find new ways to make a living. In line with Swedish national strategies on food supply there is an interest to develop commercial cyprinid fisheries. In the Bothnian Bay in the northern part of the Baltic Sea, annual catches have increased from zero-catches 2018–30 tonnes 2021. To aid a sustainable development of these cyprinid fisheries that target mainly bream (*Abramis brama*) and ide (*Leuciscus idus*), we study catch efficiency of target species and bycatch in different gears and seasons using logbook data from the Bothnian Bay. Using cameras, we also assessed bycatch rates. To assist the sustainability of the fishery we develop potential stock indicators. Our results suggests that larger gear (pound-nets) are more effective in catching bream, and that the proportion of bycatch decreased with gear size, being < 10% in the largest gear, which is similar or lower than many other Baltic Sea fisheries. By-catches of salmon is of concern in the Bothnian Bay, but the camera study indicates that salmon bycatches are sporadic. Catch per unit effort (CPUE) of bream was highest in spring and fall, and we conclude that site specific median CPUE is the most suitable stock abundance indicator. The size indicator *L90*, the 90th percentile of the length distribution, was similar among areas and we propose it as a suitable indicator of the demographic structure of the targeted bream stocks. Our results provide reference points for relatively unfished conditions, but as the study was based on mainly fishery dependent data, it is important to also include fishery independent data to assess ecosystem effects of a future and intensified cyprinid fishery.

## 1. Introduction

In the Baltic Sea, a brackish inland sea, several of the most valuable commercial fish species, like eel (*Anguilla anguilla*), Atlantic salmon (*Salmo salar*), cod (*Gadus morhua*), Atlantic herring (*Clupea harengus*) and pikeperch (*Sander lucioperca*) have decreased in abundance over the last decades (Olsson, 2019; ICES, 2020a; ICES, 2020b) resulting in fishing closures and decreased quotas. In addition, species like herring, salmon and whitefish (*Coregonus maraena*) also face problems with high levels of contaminants in the Baltic Sea (Tuomisto et al., 2020). Thus, there has been a reduced diversity of fish resources for small-scale coastal fishers to target and obtain income from (Bergenius et al., 2018), and profitability in the fishery is generally low (Waldo and Lovén, 2019). In addition, many of the species traditionally targeted by fisheries in the Baltic Sea as whitefish, herring, and cod are likely sensitive to climate change and eutrophication, indicating that population recovery might be slow, or not possible in the Baltic Sea (HELCOM, 2021). There is hence a quest from fishers and authorities to find new target species to secure income and local food production (EU, 2014; Swedish Government, 2016).

Cyprinid fisheries substantially contribute to fish production for human consumption in freshwaters in Eurasia (Bnińska, 1991; Danilov et al., 2020), but are marginal in marine environments (Bergenius et al., 2018; ICES, 2020a). While bream (*Abramis brama*), roach (*Rutilus rutilus*) and ide (*Leuciscus idus*) used to be important complements as human food in Sweden a century ago (Svärdson, 1965; Schreiber et al., 2003; Bonow and Svanberg, 2013), they still are in central and eastern Europe (Bnińska, 1991; Valoukas and Economidis, 1996; Treer et al., 2003;

* Correspondence to: Swedish University of Agricultural Sciences, Dept. Aquatic Resources, P.O. Box 7015, 750 07 Uppsala, Sweden.
*E-mail address:* orjan.ostman@slu.se (Ö. Östman).

https://doi.org/10.1016/j.fishres.2023.106829
Received 8 September 2022; Received in revised form 16 August 2023; Accepted 19 August 2023
Available online 29 August 2023

Danilov et al., 2020). As these species tend to be abundant in eutrophic and warm waters, their abundances have increased in many of the sheltered bays of the Baltic Sea (Östman et al., 2017; HELCOM, 2018). Recently, there has been an increased interest from coastal fishers in Finland and Sweden to target cyprinids, primarily bream, but also roach and ide. In the Archipelago Sea between Åland and Finland, landings of bream and roach have increased from 100 to around 800 tonnes during the 2010's (Lappalainen et al., 2019). In the Swedish part of the Bothnian Bay landings in 2021 was 30 tonnes, from basically no landings before 2019. As bream dominates cyprinid catches in the Bothnian Bay (93%), we here mainly focus on bream fisheries.

A new fishery targeting bream do, however, require caution and scientific evaluation to prevent overfishing or undesired ecosystem effects. Beside generic management targets about viable populations there are currently no fishing regulations or management targets related to any cyprinid fisheries in Sweden. Fishing gears used to target bream, fyke- and pound-nets, may however, also catch other and potentially more vulnerable and regulated species, and there are hence local restrictions regarding what type of fishing gears that are allowed.

Little is known about the biology and life-history of bream in the Baltic Sea. Bream shows considerable variation in growth and maturity patterns across its distributional range (Sundblad et al., 2020). They are, relative many commercial species, slow growing and reach 40–60 cm (1–2.5 kg) at ages 15–20, mature between an age of 3–10 years, and there seem to be small differences between sexes (Sundblad et al., 2020). In the Baltic Sea, they migrate in spring to spawn in shallow warmer waters, and may also aggregate in schools during fall. Adults feed mainly on zoobenthos in soft bottom areas. The species seems almost absent in gut-analyses of common fish predators like perch (*Perca fluviatilis*) and pike (*Esox lucius*) (Jacobson et al., 2019) or common apex predators like great cormorants (*Phalacrocorax carbo*) (Boström et al., 2012) and grey seal (*Halichoerus grypus*) (Svensson, 2021) in the Baltic Sea. Bream is a target-species for biomanipulations in eutrophic lakes and ponds to reduce nutrient levels and improve water quality, due to its locally high abundance, feeding on herbivores, and causing resuspension of sediments (Bernes et al., 2015). As data and knowledge on the stock-structure of cyprinid fish in general is largely missing, there is an apparent risk for local overexploitation, in turn resulting in further degraded ecosystems. Hence, there is a need to develop indicators that can track stock changes and serve as early warning signals of over-exploitation in combination with management targets that reflect sustainability in the fishery.

In this study, we use data on total catch and landings from small-scale commercial fishers along the Swedish coast of the Bothnian Bay using pound-nets targeting the cyprinid species bream and ide, to analyse the catch, bycatch and size distributions of cyprinids (only bream for size distributions). More specifically, we focused on 1) catch efficiency and 2) bycatch of non-cyprinids in the different gears (pound- and fyke-nets of different sizes) over different seasons. We also analysed 3) length and age distributions of the landings and length-at-age of bream, and 4) developing abundance- and size indicators for these relatively unfished conditions to be used as reference points in future stock assessment and to develop management targets for fishers or authorities. In addition, bycatch of wild salmon is of concern in the area as the major natural spawning rivers (Pite, Kalix and Torne rivers) in the Baltic Sea have their outlets in the area (ICES, 2021a; b). Therefore, we complemented fishery dependent data with a camera study of a pound-net without a fishing house placed at the outlet of the Kalix River to assess the propensity of salmons to enter a pound-net targeting cyprinids.

## 2. Methods

### 2.1. Catch data

Data was collected in collaboration with four small-scale fishing companies along the Swedish coast of the Bothnian Bay (Suppl. Fig. S1) through a data collection scheme coordinated by the NGO 'Race For The Baltic'. During 2019 total catches in kilograms of all fish species were recorded in three pound-nets of different heights, *i*) 1.5 m, *ii*) 3 m, and *iii*) 4 m (Suppl. Fig. S2). All gears were tested in two different sites in the Bothnian Bay, Råneå and the Töre (Suppl. Fig. S1). Within each site, there was originally two replicates of each gear, but due to algal overgrowth, sabotage, destruction and thefts, there was only one replicate of each gear except for the 4 m pound-nets (two replicates) at the end of the season. Fishers also tried a smaller 1 m fyke-net, but these were quickly overgrown with algae, and hence, not further used. Gears were set out after ice break-up in mid-May 2019 and removed in the beginning of August 2019. Gears were emptied every 3–7 days depending on the amount of catch. We calculated catch per unit effort (CPUE) as the total catch in kilogram divided by number of days since last emptying the gear.

Based on experiences from 2019, the fishing companies only used the 4 m high pound-nets but added two 60 mm ('knot-to-knot') escape-windows for smaller fish 2020–2021. Eight pound-nets were used 2020, of which five were in the River Töre outlet and one at Råneå studied also in 2019, and two new sites (Kråknäset and Sundomsfjärden). The number of fishing gears (sites) increased to 17 in 2021, of which seven was in the River Töre outlet, and with seven new sites (Fig. 3; Suppl. Fig. S1). Each year fishers reported for each sampling occasion the total catch in kilogram of different cyprinid species, and discarded catch (kg) of unwanted cyprinids (e.g. roach). Note that CPUE for 2020–2021 includes only landed cyprinids and not discard. Fishers reported bycatch of perch in kilogram, whereas bycatch of pike, pikeperch, brown trout (*Salmo trutta*), salmon, whitefish, and of mammals and birds, were reported as number of individuals.

Actual fishing periods differed between sites and we therefore divided catches into three seasons: May-June (spring), July-August (summer), and September-November (fall, only 2020), to compare catches over the year. From each site, at least 100 random breams from one landing event (excluding discarded fish) in spring were size measured. In Töre, landings from the five gears were 2020 pooled into one sample of 637 breams. At Råneå 2020 there was also a sample of breams measured in the fall. The fishers were supposed to measure the fish to the nearest centimetre, but due to a misunderstanding, breams were measured in 10 cm interval at Råneå. Here the size difference between the smallest and largest measured breams was 40 cm, and the number of breams in each 10 cm class was relatively even so we do not think the 10 cm classes will impact the results more than ± 5 cm compared to 1 cm intervals.

### 2.2. Age and sex determination

In fall 2020 and spring 2021, we collected 21 and 54 individuals, respectively, of bream from the Töre area that were sent to the laboratory of the Swedish University of Agricultural Sciences at Öregrund for age (all samples) and sex determination (only samples from spring 2021). The lapilli otoliths were removed and embedded in black polyester resin, sectioned (0.4 mm) with a high variable speed cutting machine (Struers Acutom-50) and stained by etching the slices for 40 s in 1% hydrochloride acid and stained for 3.5 min with Toluidine blue. The age was determined by counting seasonal growth zones under a microscope with transmitted light with 10–40x magnification (SLU, 2012). We fitted the individual length at age to von Bertalanffy's growth functions using the R package '*fishmethods*' (Nelson, 2021). From the age distribution between age 11 and 30 (the most common ages in the sample) we estimated total instantaneous mortality (Z) using the Chapman-Robson method in the '*FSA*' package for R (Ogle et al., 2022).

### 2.3. Camera study

During 2020 we had a special 4 m pound-net installed in the outlet of the River Kalix (Suppl. Fig S1), that is one of the major Swedish rivers for spawning of wild Atlantic salmon (ICES, 2021a). To not interfere with salmon spawning migration the pound-net did not have a fish house that caught the fish. Instead, the gear was open and equipped with a camera to record all fish entering and passing through the gear. The camera used was a Mobius ActionCam Original with wide-angle lens (Lens C2), (www.mobius-actioncam.com). The Mobius C2 wide-angle lens allow for a field of view of 132 degrees. Video recording resolution was WVGA (848 × 480) with a frame rate of 5 fps. Video data was recorded as MP4 files onto 64 GB Micro SD memory cards. The combination of memory card storage capacity, resolution and frame rate allow for a theoretical total recording time of 96 h. However, recording time using only the internal battery limit recording time to two hours. To allow for longer recording times an Andersson standard 30000 mAh 5 V USB power-bank was added together with a USB power-bank using a keep-alive-load (www.sotabeams.co.uk). The keep-alive-load prevents the power-bank to switch off at low currents, as when the internal Mobius camera battery is fully charged. The Mobius camera and keep-alive-load was fixed to the power-bank using adhesive Velcro tape. The combined camera system setup could then record continuously for up to 72 h. The camera system was fitted inside a 4" acrylic watertight ROV enclosure from Blue Robotics (www.bluerobotics.com). In order to make the setup negative buoyant, the acrylic tube was shortened to 20 cm and equipped with straps to allow it to be fastened in the mesh in the bottom part of the pound-net. The camera was run 24 h a day between 22 June and 6 July 2020, during the second half of the salmon migration, except for the time to change memory card and batteries every second day. Although light conditions during artic night summer was good enough to detect fish swimming into the gear, it was not strong enough to identify some of the passing fish. The recordings from the camera was analysed using the software BORIS (Behavioural Observation Research Interactive Software) version v. 7.9.7 (Friard and Gamba, 2016). All recordings were visually analysed by one person (SL) at multiple speed, and when a fish was detected the time and when possible, species, was noted.

### 2.4. Statistical analysis

We used R 4.0.4 (R Core Team, 2021) for all statistical analyses. For the 2019 data we used generalised linear mixed models (GLMM) to analyse differences in CPUE with gear type (1.5, 3 and 4 m gears) as fixed effect and each individual pound-net nested under site (Råneå or Töre) as random factor to account for repeated measures. We log-transformed CPUE of bream, perch and the ratio of by-catch to target catch (cyprinids) to better fit the Gaussian distribution (see Suppl. Fig. S3). For ide and pike, we instead used negative binomial distributions of (untransformed) CPUE with a logit link function due to many zero-observations. We fitted all models using the *lme4*-function for R (Bates et al., 2015). Statistical significance of explanatory variables was tested according to Satterthwaite's method using the 'lmerTest'-function in R (Kuznetsova et al., 2017) and we assessed model fits from QQ-plots (Suppl. Fig. S3). The QQ-plots for especially perch and whitefish indicated skewed distributions.

From 2020–2021, catch data were from 4 m pound-nets only. To analyse seasonal variation, we used data from 2020, as catch data from 2021 was almost only from spring (May-June). We analysed CPUE of bream, ide, perch, pike, whitefish, and the ratio perch-cyprinids using general linear models (GLM) with season and site (i.e. each gear) as explanatory fixed factors. For bream we also analysed differences in CPUE between years (2020 and 2021) using only spring data in a GLM with site and year as explanatory variables. All CPUE and perch-cyprinid ratios were log-transformed prior to analyses to better fit a Gaussian distribution (see Suppl. Fig. S4). We also used GLMs for analysing differences in size distributions but with total length of individual (untransformed) breams as dependent variable and site as a fixed factor (only during spring) or season as a fixed factor (only for Råneå 2020 and Borgarudden 2021).

### 2.5. Stock indicators

To develop potential indicators for bream fisheries we calculated means and the 25th (C25), 50th (median) and 75th (C75) percentile of CPUE (Sundblad et al., 2020) for each site and season. In addition, we calculated the coefficient of variation (CV = 100 *SD/Mean) of CPUE, which is not a stock indicator but indicates the variability in CPUE within a site and season.

To study differences in size distributions, we calculated several size-based indicators proposed to relate to fishing pressure and management of data-limited stocks (Froese, 2004; Greenstreet et al., 2011; Shephard et al., 2011; Fitzgerald et al., 2018). We calculated mean length and the 10th, 50th (median) and 90th percentile of length distributions (L10, L50 and L90, respectively; Shin et al., 2005; Sundblad, . et al., 2020), and a number of indicators that rely on threshold values. The 'Large Fish Index', *LFI,* was calculated as the proportion of breams larger than either 30 or 40 cm (Greenstreet et al., 2011; Shephard et al., 2011), $L_{mega}$ as the mean length of breams larger than 40 cm (Froese, 2004; Fitzgerald et al., 2018), and $L_{max}$ as the mean length of the largest 10 percentile of breams (Fitzgerald et al., 2018; Miethe et al., 2019). The threshold sizes of 30 and 40 cm were set arbitrary under the assumption that at 30 cm we think the majority of individuals have matured (Sundblad et al., 2020; this study), and that 40 cm could represent 'mega-spawners' (see Froese, 2004). For calculating $L_{max}$ we here use the 10 percentile of largest breams instead of the 5th largest percentile often used in offshore (trawl) fisheries (Shin et al., 2005; Miethe et al., 2019) motivated by the need to reach a sufficient sample size (individuals), which is much lower in pound-nets compared to trawls, to avoid indicator values prone to sampling variation.

## 3. Results

An overview of the main results is available in Table 1 that shows significant variation in bream catch per unit effort (CPUE) between gears, sites and years. In contrast, catches of ide and bycatch species were much lower and did not show significant spatiotemporal variation (Figs. 1, 2), but distributions were skewed (Suppl. Fig. S3), so care is required when interpreting results for these species.

### 3.1. Catches in different gear types

For the 2019 data there was an increase in CPUE of breams with increasing gear size (Table 1, Fig. 1a), from on average around 1 kg bream/day to 42 kg breams/day in the 4 m pound-net. There were substantially smaller catches of ide (average 0.6 kg/day) with no difference in CPUE between gear types ($F_{2,3.8}$ = 1.0, p = 0.4; Fig. 1b).

**Table 1**
Overview of the main statistical results from the study.

| Year | Variable | Test variable | F-value | Significance | Results |
|---|---|---|---|---|---|
| 2019 | Bream CPUE | Gear type | $F_{2,3.6} = 12$, | p = 0.02 | Fig. 1a |
| 2019 | %Bycatch | Gear type | $F_{2,4.4} = 7.0$ | P = 0.04 | Fig. 1d |
| 2020 | Bream CPUE | Season | $F_{2,80} = 32$ | p < 0.001 | Fig. 2a |
| 2020 | Perch CPUE | Season | $F_{2,80} = 1$ | p = 0.4 | Fig. 2c |
| 2020 | %Bycatch | Season | $F_{2,80} = 0.1$ | P = 0.9 | Fig. 2d |
| 2020 | Pike CPUE | Season | $F_{2,80} = 2.6$ | p = 0.08 | Fig. 2e |
| 2020–2021 | Bream CPUE | Site | $F_{17,184} = 21$ | p < 0.001 | Fig. 3 |
| 2020–2021 | Bream CPUE | Year | $F_{1184} = 16$ | p < 0.001 | Fig. 3 |
| 2020–2021 | Length | Season | $F_{1738} = 38$ | p < 0.001 | Fig. 4a |
| 2020–2021 | Length | Year | $F_{1,1754} = 29$ | p < 0.001 | - |
| 2020–2021 | Length | Site | $F_{3, 1754} = 334$ | p < 0.001 | Fig. 4b |

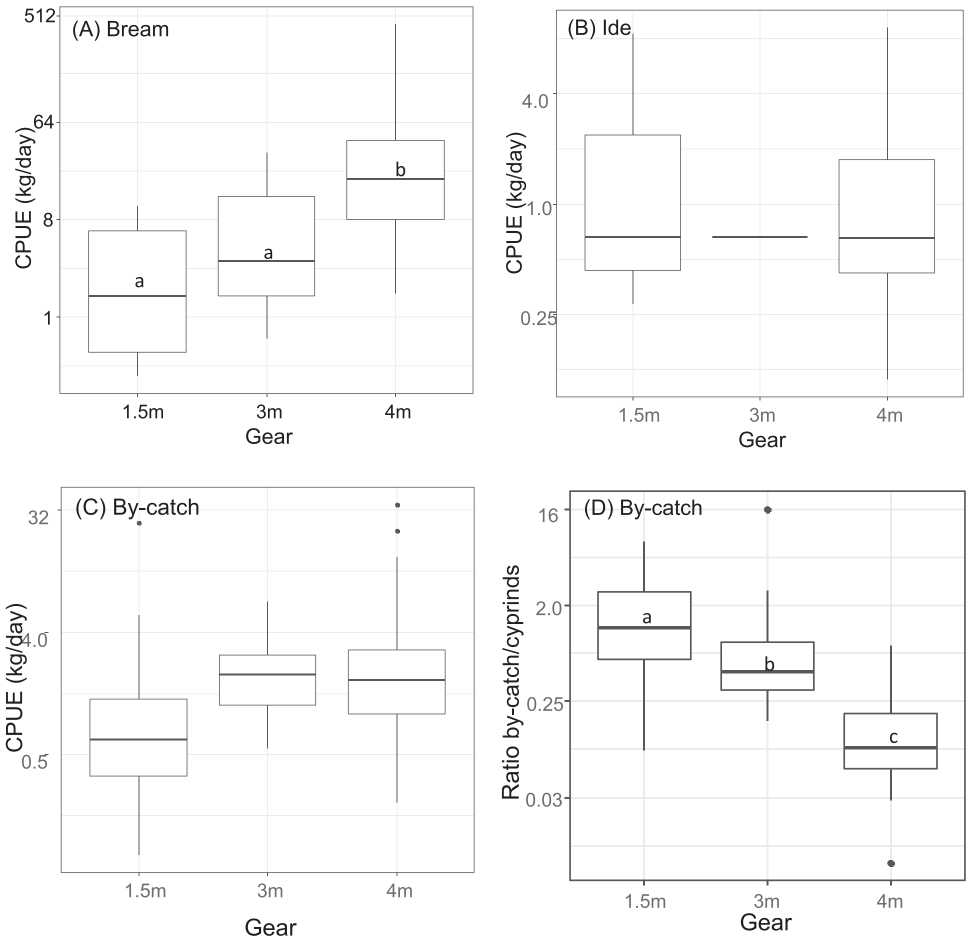


**Fig. 1.** Box-whisker plots of catch per unit effort (CPUE, kg/day) of (A) bream, (B) ide, and (C) the summed by-catch of perch and pike (numbers/day) in gears of different size. (D) shows the ratio of by-catch of perch and pike (numbers) to total cyprinid catch in kg. Boxes indicate first (25%) and third (75%) quartiles, the bar the median and whiskers 1.5 *the distance between the first and third quartiles. Different letters in lower case (a-c) indicate significant differences ($p < 0.05$) in post-hoc tests, and hence, no letter or the same latter indicate no significant ($p > 0.05$) difference between gears. Note log2-scale on the y-axes.

Catches of smaller unwanted cyprinid species (mainly roach) was on average 1 kg/day and did not differ between different gears ($F_{2,61} = 1.7$, $p = 0.2$). Neither bycatch of perch, nor pike differed significantly between gear types in absolute numbers ($F_{2,61} = 2.2$, $p = 0.1$, Fig. 1c). Hence, the ratio of by-catch (in numbers) to cyprinid (bream and ide) catch (in kg) decreased with gear size (Table 1, Fig. 1d).

### 3.2. *Temporal and spatial differences in catch efficiency*

In the 4 m pound nets the landings (excluding unwanted sizes) of bream differed between sites and seasons, from well above 100 kg/day at Råneå to 2–5 kg/day at Töre (Tables 1, 2, Figs. 2, 3). In 2020, CPUE was on average highest in fall (one site only) and lowest in summer (Table 1, Fig. 2a). The average catch of ide was still low, 0.70 kg/day, and did not differ between seasons ($F_{2,80} = 0.8$, $p = 0.5$, Fig. 2b). Discarded cyprinids was on average 0.3 kg/day due to the escape windows. Bycatch of perch averaged 0.7 kg/day and did not differ between seasons (Table 1, Fig. 2c). Perch (in kg) as proportion to cyprinid catch (on average 1.9%) did not differ between seasons (Table 1, Fig. 2d). The average by-catch of pike was 0.48 pikes per day, and showed a weak tendency to be highest in spring (Table 1, Fig. 2e). Only one salmon was reported from the pound-nets, and whitefish constituted most of the salmonid bycatch, with an average of 0.22 whitefish per day confined to June and July (Fig. 2f). One ringed seal, but no birds were reported as bycatch in the 4 m pound-nets.

During spring 2020 and 2021, the CPUE differed between sites for both bream (Table 1, Fig. 3) and ide ($F_{17,184} = 4.5$, $p < 0.001$), while differences between years was only evident for bream, with higher CPUE in 2020 than 2021 (Table 1, Fig. 3), but not for ide ($F_{1184} = 1.7$, $p = 0.2$). Bycatches differed between sites (pike: $F_{17,184} = 8.8$, $p < 0.001$; perch: $F_{17,184} = 8.8$, $p < 0.001$; whitefish: $F_{17,184} = 4.8$, $p < 0.001$) and years for whitefish ($F_{1184} = 94$, $p < 0.001$), but not for pike ($F_{1184} = 1.1$, $p = 0.3$) and perch ($F_{1184} = 2.4$, $p = 0.12$).

### 3.3. *Camera study*

From the filmed entrance of the open pound-net without a fish house during the two weeks, we could see 556 passing fish of which we identified 364 individuals (65% of all fish). We identified 291 fish as bream or ide (52%). There were 61 identified perch (11%), and nine pike (1.6%). We only one identified one fish with certainty as a salmon or trout, but additionally two fish were uncertain and may have been salmon, trout or grayling (*Thymallus thymallus*). Due to the poorer visual conditions during nights, there 192 (35%) of the fish that we were not able to identify. However, as these fish were generally small, < 25 cm (likely bleak, herring, small cyprinids or perch), we are confident that none were a migrating salmonid fish.

### 3.4. *Size and age distributions of bream*

Råneå and Borgarudden were the only sites with length data for breams from both spring and fall (in 2020 and 2021, respectively). Breams in the landings from these two sites were significantly larger in spring (mean 39 cm) than in fall (mean 35 cm; Table 1, Fig. 4a). For all sites and both years, the length distributions of bream in the landings during spring and early summer (late May to early July) differed significantly between sites and years (Table 1, Fig. 4b), from on average 41 ± 0.3 (SE) cm in 2020–39 ± 0.2 (SE) cm in 2021.

The average age of the 75 aged determined breams from Töre was 18.4 years with an average length of 43.7 cm (Fig. 5). The oldest bream

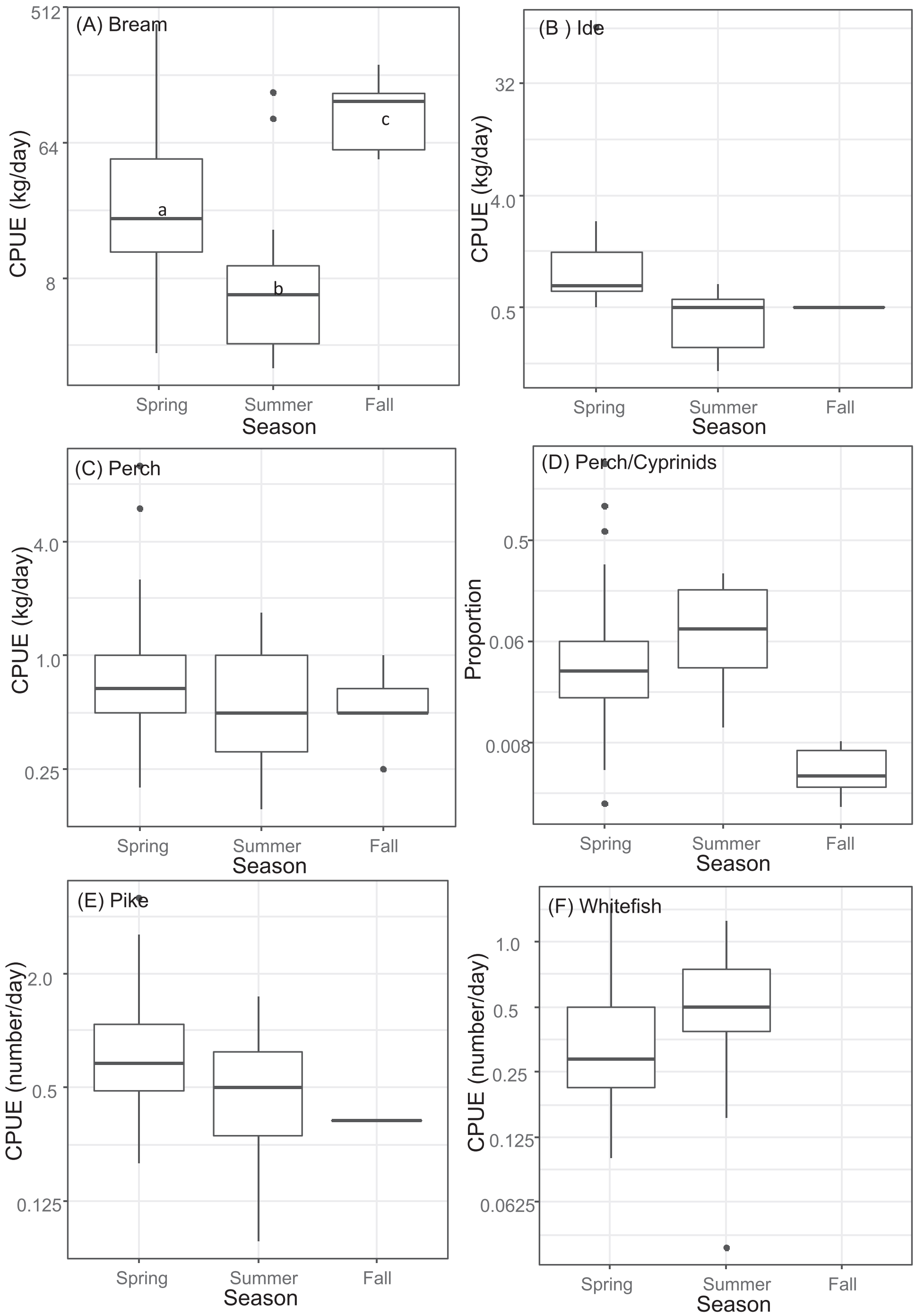


**Fig. 2.** Box-whisker plots of CPUE (catch per day) of (A) bream, (B) ide, (C) perch, (D) perch-to cyprinid ratio, (E) pike, and (F) whitefish during different seasons in the Bothnian Bay 2020. Boxes indicate first (25%) and third (75%) quartiles, the bar the median and whiskers 1.5 *the distance between the first and third quartiles. Different letters in boxes indicate statistically significant differences. Different letters in lower case (a-c) indicate significant differences ($p < 0.05$) in post-hoc tests Note the log2-scale on the y-axes.

**Table 2**
Indicators of bream CPUE (abundance) for gears of different size and different seasons in 2019. Mean is average CPUE, C25, median and C75 indicate the 25th, 50th, and 75th percentiles of CPUE, respectively, and CV is the coefficient of variation of the mean CPUE. N is the number of times a gear type were emptied during a season.

| Gear | Site | Season | N | Mean | C25 | Median | C75 | CV |
|---|---|---|---|---|---|---|---|---|
| 1.5 m | Råneå | Spring | 1 | 10.7 | 10.7 | 10.7 | 10.7 | NA |
| 1.5 m | Töre | Spring | 8 | 3.07 | 0.68 | 1.63 | 4.83 | 1.05 |
| 1.5 m | Töre | Summer | 5 | 0.08 | 0 | 0 | 0 | 2.24 |
| 3 m | Råneå | Spring | 3 | 17.42 | 9.47 | 15.6 | 24.4 | 0.87 |
| 3 m | Råneå | Summer | 5 | 3.00 | 0.64 | 1.11 | 2.27 | 1.51 |
| 4 m | Råneå | Spring | 7 | 64.61 | 19.9 | 32.7 | 52.8 | 0.76 |
| 4 m | Råneå | Summer | 10 | 15.76 | 32.2 | 53.5 | 81.3 | 1.22 |
| 4 m | Råneå | Fall | 4 | 40.00 | 7.18 | 10.9 | 16.3 | 0.74 |
| 4 m | Töre | Spring | 15 | 76.79 | 11.3 | 30 | 70.3 | 1.70 |
| 4 m | Töre | Summer | 10 | 9.38 | 3 | 4.42 | 12 | 1.16 |

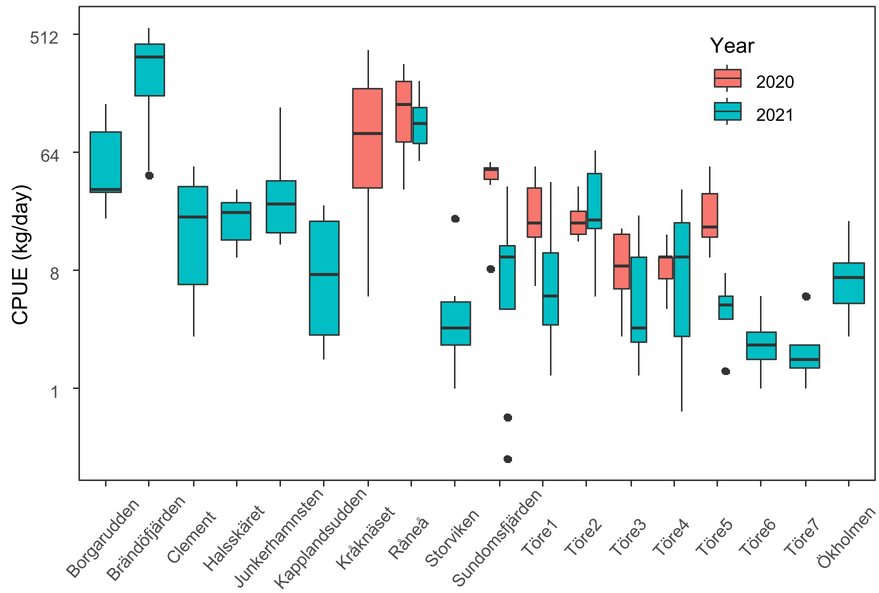


**Fig. 3.** Box-whisker plots of CPUE (catch per day) of bream at 18 sites in the Bothnian Bay 2020–2021. Boxes indicate first (25%) and third (75%) quartiles, the bar the median and whiskers 1.5 *the distance between the first and third quartiles. Note the log2-scale on the y-axis. See Fig S1 for a map showing the location of the sites.

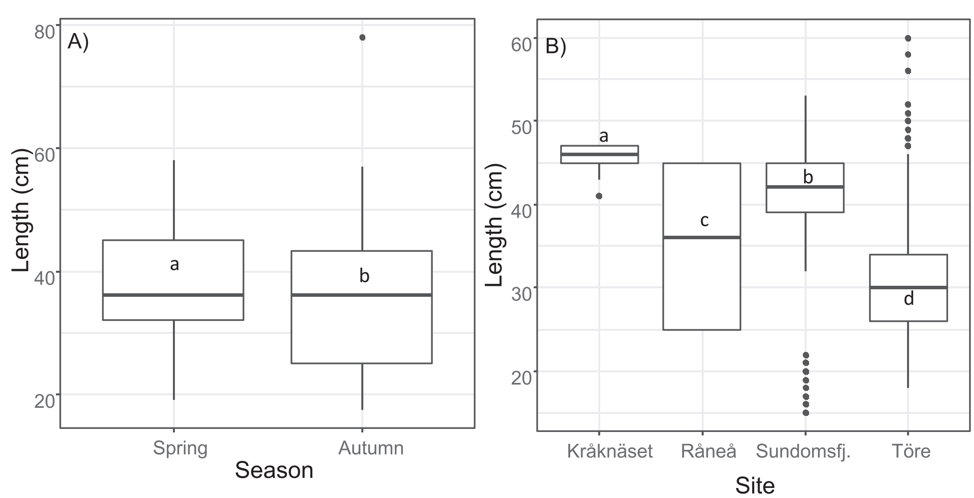


**Fig. 4.** Box-whisker plots of length of bream in catch (A) during different seasons, and between sites (B) in spring and early summer 2020–2021. Boxes indicate first (25%) and third (75%) quartiles, the bar the median and whiskers 1.5 *the distance between the first and third quartiles. Different letters in lower case indicate significant differences ($p < 0.05$) in post-hoc tests.

was 49 years and the largest was 60 cm long, while the youngest was six years old and 26 cm. All sampled breams in spring 2020 (during spawning migration) were sexually mature. Estimated average maximum sizes ($L_{inf}$) was 52 ± 2.3 (SE) cm, and excluding the oldest (outlier) bream had little impact on that estimate ($L_{inf} = 51 \pm 2.4$ cm). There was no significant difference in length at age between sexes of bream sampled in spring 2021 ($F_{1,51} = 0.6$, $p = 0.4$). Based on the sampled age distribution of the catch, the Chapman-Robson estimate (Z) of instantaneous mortality rate was $Z = 0.12$ between age 11 and 30, when it can be assumed all individuals are > 30 cm and recruited to the fishery.

### 3.5. Abundance and size indicators

Indicators of abundance should preferably have high precision, i.e. low sampling variation, here inferred as coefficient of variation (CV). Catch per unit effort (CPUE), of bream showed a CV within gears, seasons and sites well above 1 in some cases (Table 2), indicating that mean CPUE may be sensitive to outliers. Median CPUE showed a substantial deviance from mean CPUE, which indicate that distributions of CPUE are skewed. In the 4 m pound-net 2020, median CPUE of bream was highest in spring and fall (Figs. 1, 2), but there was no clear difference in CV between spring and summer (Table 3, only one site in fall). Thus, based on sampling distributions alone, there is no reason to exclude or prefer any season over another Although the mean CPUE of bream differed between years (Table 3, Fig. 3,), there was no significant difference in median CPUE between 2020 and 2021 ($F_{1,20} = 1.2$, $p = 0.3$).

Median and mean values of the size distributions among all sites and seasons varied between 30 and 46 cm and 25–45 cm, respectively, and *L10* from 17.5 to 43 cm (Table 4). Also, both the Large Fish Indices, proportion of fish > 30 and > 40 cm ($LFI_{30}$ and $LFI_{40}$), showed considerable differences between sites and seasons, and ranged between 40%– 100% and 13%– 100%, respectively. The size indicator

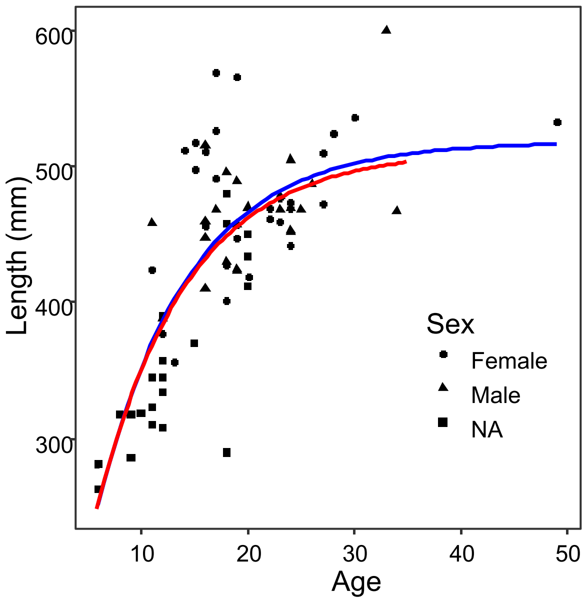


**Fig. 5.** Length at age of 75 breams sampled in the Bothnian Bay. Circles are females and triangles are males sampled in spring 2020, whereas squares are non-sexed breams sampled in fall 2019. The blue solid line is the best fit of all observations to von Bertalanffy's growth function and the red line when the oldest (age 49) bream is excluded.

measuring the length of the largest fish, $L_{90}$, $L_{max}$, and $L_{mega}$ showed smaller ranges across sites, in most cases spanning 44–52 cm, 45–55 cm and 43–47 cm, respectively (Table 4), however, $L_{90}$ and $L_{max}$ were considerable lower at Töre 2021 compared to other sites and years (37 cm and 42.5 cm, respectively, Table 4).

## 4. Discussion

Cyprinid fish are predicted to increase in abundance in the northern hemisphere due to climate change and eutrophication (Olsson et al., 2012; Östman et al., 2017; Danilov et al., 2020; HELCOM, 2021), and may become more important for fisheries, not only in the Baltic Sea. Here bream dominated cyprinid catches as escapement windows in the gears resulted in low catches of the smaller, but common, roach. The considerably larger ide is present in the area but catches were low. This could be the result of the gear types or sites in this study were not suitable for ide, or that the spawning migration of ide occurred before deployments of gears. Consequently, we here mainly focus our discussion on bream.

### 4.1. Bycatch

In the largest gear, the bycatch ratio of non-cyprinid fish were much less than 10%. On average, bycatch of non-target fish in Swedish fisheries is estimated to be around 10%, but considerably higher in demersal fisheries (Bergenius et al., 2018). In the vendace trawl fishery in the Bothnian Bay, bycatches of whitefish is on average 8% (Naddafi and Olsson, 2018). Bycatches of birds and mammals were also very low with only one seal being reported. Thus, in comparison with other fisheries in the area, the bycatch of non-target species in the coastal cyprinid fishery cannot be considered as high, and in contrast to the trawling fishery and often gillnets, fish in pound-nets can often be released alive (Fraser et al., 1965; Hattula et al., 1995).

In this area of the Baltic Sea, bycatches of salmon are of special concern. Salmon fisheries are only allowed for a couple of weeks in early summer by a limited number of licensed fishers to prevent overfishing of

**Table 3**
Indicators of bream CPUE (abundance) for different sites and seasons in 2020. Mean is average CPUE, C25, median and C75 indicate the 25th, 50th, and 75th percentiles of CPUE, respectively, and CV is the coefficient of variation of CPUE. N is the number of times a gear type was emptied during a season.

| Site | Year | Season | N | Mean | C25 | Median | C75 | CV |
|---|---|---|---|---|---|---|---|---|
| Kråknäset | 2020 | Spring | 11 | 132 | 35.2 | 89.0 | 204 | 0.93 |
| Råneå | 2020 | Spring | 7 | 154 | 76.7 | 150 | 221 | 0.63 |
| Råneå | 2020 | Summer | 2 | 117 | 105 | 117 | 128 | 0.28 |
| Råneå | 2020 | Fall | 7 | 110 | 57.5 | 120 | 138 | 0.55 |
| Sundomsfjärden | 2020 | Spring | 8 | 41.4 | 39.3 | 47.2 | 48.6 | 0.35 |
| Töre1 | 2020 | Spring | 8 | 25.1 | 14.3 | 18.8 | 35.0 | 0.67 |
| Töre1 | 2020 | Summer | 3 | 5.34 | 3.78 | 5.56 | 7.01 | 0.61 |
| Töre2 | 2020 | Spring | 8 | 20.3 | 15.0 | 18.3 | 22.8 | 0.35 |
| Töre2 | 2020 | Summer | 3 | 3.29 | 2.15 | 2.31 | 3.93 | 0.60 |
| Töre3 | 2020 | Spring | 8 | 9.71 | 5.75 | 8.75 | 15.0 | 0.55 |
| Töre3 | 2020 | Summer | 3 | 9.56 | 6 | 10.0 | 13.3 | 0.77 |
| Töre4 | 2020 | Spring | 7 | 8.96 | 6.88 | 10.0 | 10.0 | 0.39 |
| Töre4 | 2020 | Summer | 3 | 5.08 | 3.78 | 5.56 | 6.62 | 0.57 |
| Töre5 | 2020 | Spring | 8 | 23.2 | 14.3 | 17.5 | 30.8 | 0.59 |
| Töre5 | 2020 | Summer | 3 | 7.49 | 6.24 | 6.92 | 8.46 | 0.30 |
| Borgarudden | 2021 | Spring | 7 | 65.5 | 31.7 | 33.3 | 95.8 | 0.79 |
| Borgarudden | 2021 | Summer | 5 | 72.0 | 25.0 | 53.3 | 125 | 0.87 |
| Brändöfjärden | 2021 | Spring | 13 | 313 | 173.4 | 341 | 435 | 0.55 |
| Clement | 2021 | Spring | 9 | 19.9 | 5 | 16.7 | 33.3 | 0.91 |
| Halsskäret | 2021 | Spring | 8 | 20.9 | 13.5 | 22.2 | 26.2 | 0.39 |
| Junkerhamnsten | 2021 | Spring | 8 | 39.8 | 15.6 | 26.7 | 38.8 | 1.08 |
| Kapplandsudden | 2021 | Spring | 8 | 8.63 | 1.25 | 2.83 | 17.5 | 1.18 |
| Kapplandsudden | 2021 | Summer | 3 | 1.47 | 0.42 | 0.83 | 2.20 | 1.27 |
| Råneå | 2021 | Spring | 8 | 117 | 75.0 | 108 | 142 | 0.49 |
| Storviken | 2021 | Spring | 6 | 5.64 | 2.125 | 2.92 | 4.58 | 1.27 |
| Sundomsfjärden | 2021 | Spring | 8 | 11.1 | 5.775 | 10 | 12.3 | 0.98 |
| Töre1 | 2021 | Spring | 10 | 9.69 | 3.08 | 5 | 10.9 | 1.16 |
| Töre2 | 2021 | Spring | 10 | 29.3 | 16.6 | 19.4 | 45.0 | 0.77 |
| Töre3 | 2021 | Spring | 10 | 7.13 | 2.23 | 2.92 | 10.0 | 1.00 |
| Töre4 | 2021 | Spring | 10 | 12.1 | 2.5 | 10.0 | 19.1 | 0.94 |
| Töre5 | 2021 | Spring | 5 | 4.29 | 3.33 | 4.29 | 5 | 0.53 |
| Töre6 | 2021 | Spring | 5 | 2.50 | 1.67 | 2.14 | 2.67 | 0.61 |
| Töre7 | 2021 | Spring | 5 | 2.25 | 1.43 | 1.67 | 2.14 | 0.71 |
| Ökholmen | 2021 | Spring | 8 | 8.13 | 4.5 | 7.11 | 9.33 | 0.68 |

**Table 4**
Size indicators of bream at different sites and seasons in 2020. Mean is average length (cm), $L_{10}$, Median and $L_{90}$ indicate the 10th, 50th, and 90th percentiles of the size distributions, respectively. LFI is the proportion of fish (in numbers) larger than 30 and 40 cm. $L_{mega}$ is the mean length of breams larger than 40 cm. $L_{max}$ is the mean length of the largest 10 percentile of breams. N is the number of breams measured at each site. L_CV is the coefficient of variation in the length distribution for each site and season.

| Year | Site | Season | Mean | $L_{10}$ | Median | $L_{90}$ | $LFI_{30}$ | $LFI_{40}$ | Lmega | Lmax | N | L_CV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | Råneå | Spring | 35.6 | 25 | 36 | 45 | 0.71 | 0.31 | 45.0 | 45.0 | 200 | 0.22 |
| 2020 | Råneå | Fall | 29.9 | 17.5 | 25 | 45 | 0.40 | 0.17 | 45.0 | 45.0 | 190 | 0.30 |
| 2020 | Kråknäset | Spring | 45.7 | 43 | 46 | 47 | 1.00 | 1.00 | 45.7 | 47.0 | 227 | 0.04 |
| 2020 | Sundom | Spring | 45.1 | 40 | 45 | 50 | 1.00 | 0.90 | 46.0 | 52.3 | 100 | 0.11 |
| 2020 | Töre | Spring | 31.2 | 24 | 29 | 44 | 0.49 | 0.13 | 46.1 | 47.5 | 637 | 0.24 |
| 2021 | Råneå | Spring | 33.2 | 25 | 36 | 45 | 0.56 | 0.23 | 45.0 | 45.0 | 200 | 0.24 |
| 2021 | Borgarudden | Spring | 41.6 | 32 | 41 | 52 | 0.96 | 0.66 | 46.5 | 54.9 | 151 | 0.20 |
| 2021 | Borgarudden | Fall | 39.8 | 30 | 40 | 51 | 0.97 | 0.51 | 46.6 | 54.4 | 200 | 0.21 |
| 2021 | Brändö | Spring | 44.1 | 35 | 45 | 49 | 1.00 | 0.87 | 45.7 | 50.4 | 227 | 0.11 |
| 2021 | Sundom | Spring | 38.7 | 21 | 41 | 46 | 0.88 | 0.61 | 43.2 | 46.5 | 203 | 0.22 |
| 2021 | Töre | Spring | 31.2 | 25 | 31 | 37 | 0.62 | 0.074 | 45.8 | 42.5 | 202 | 0.18 |

the remaining wild stocks. In the catch data collected from fishers available to us, only one salmon was reported from a total catch of more than 54 tonnes of cyprinids. These figures rely on fishery dependent data we had no possibility to verify, and instead we used a second approach to assess bycatch. In addition to catch reports, the camera study in the river mouth of the River Kalix during the salmon migration verified a potential low bycatch of salmon, despite placed right in the migration route for the second largest wild salmon stock in the Baltic Sea (ICES, 2021a). A maximum of three salmonid fish entered the gear, of which two we were uncertain regarding species identification. This gear was set around the second half of the salmon migration period suggesting that additional salmons would likely have entered if the gear had been open earlier. As we only had one gear, the study could not be replicated, in turn casting doubts on how representative the results really are. For comparison, our results are nevertheless considerable lower than the ten salmons caught during June-July 2009 in a herring pontoon trap in the Bothnian Sea (Lundin et al., 2011). Although both catch reports and the camera study have their limits, combining them strengthen the conclusion that bycatch in general, and of salmonids in particular, would not be higher in cyprinid fisheries than in other fisheries in the region. It should be noted that all bycatch in the gears used in this study can be released alive but we have not assessed subsequent survival of released fish.

### *4.2. Abundance indicators*

In this area, bream dominates cyprinid catches whereas ide and the largely unwanted smaller roach make up around 5% of total cyprinid catches. This will likely differ in other areas of the Baltic Sea due to habitat variation and species-specific migration patterns. The largest (4 m) pound-net was as expected most effective at catching bream, and the catch reports indicate that fall and spring are the seasons with the highest catch of bream per effort, while summer is the least suitable period to target bream. There was considerable variation in the catch of bream per effort between sites as well as within sites over time, likely due to unaccounted phenological and environmental variation. Hence, reference values of abundance indicators need to be site and season specific. Due to the high within site variation in CPUE, we suggest that the median CPUE is currently the most suitable abundance indicator for bream.

### *4.3. Length indicators*

Length distributions also showed considerable variation between sites, years as well as seasons. To what degree the size distribution of breams depend on local conditions is currently unknown. However, it was mainly the proportion of smaller breams (as indicated by variation in *L10, L50* and *LFI*) that differed between year, seasons and sites, whereas the indicators aiming towards larger fish ($L_{90}$, $L_{mega}$, $L_{max}$) were more similar. This is not surprising as indicators that focus on the right-hand side of the length frequency distribution tend to be more robust to dynamic processes, such as recruitment (Kell et al., 2022). Nevertheless, we think these indicators complement each other. Whereas $L_{90}$ and $L_{max}$ depend on the size distribution of the whole catch and respond to recruitment of fish into the fishery, $L_{mega}$ is calculated for only fish > 40 cm, and may therefore respond faster to increased fishing pressure (Froese, 2004). Although $L_{mega}$ was most consistent among sites here, there is a risk for sampling errors if sample size is low (~ 100–200 individuals) due to few individuals above 40 cm. We therefore suggest to consider $L_{90}$ and $L_{max}$ as complement when comparing between sites, seasons, and over years.

The size distribution of bream in the landings in the Bothnian Bay was largely overlapping with the size distribution in catches in the Archipelago Sea (SW Finland), where the size distribution differed substantially between years (Lappalainen et al., 2019). In commercial catches of bream in the Archipelago Sea, there were more breams of 15–20 cm, which were generally missing in the Bothinan Bay. This depends on the use of selection panels in the Bothnian Bay allowing the smallest breams to escape. The use of selection panels in the Bothnian Bay cyprinid fisheries aims to facilitate the work for fishers by reducing the catch of undersized fish that (currently) cannot be used in the process chain, but also allow immature breams to escape.

### *4.4. Age structure and mortality*

The age-length key of the 75 breams indicates that the median and mean sized breams around 30–40 cm in the catch are around 8–15 years old. There was one outlier fish, aged 18 years only 29 cm long, which we expect was a hybrid between bream and either white bream (*Abramis bjoerkna*) or roach that seems to become a morphological mix of their parents (Pitts et al., 1997; Demandt and Bergek, 2009). Given the old ages and the considerable variation in length-at-age as bream grow older suggest that an age-based indicator would be informative about changes in fishing mortality. In contrast to size-based indicators, age-based indicators require specialist knowledge and age reading is expensive, but is something that should be considered also in the future.

The smallest bream in the catch (∼25 cm) was around 5 years old. Hence, the breams targeted in this fishery are likely older than many other commercial species in the Baltic Sea that are often in the age 2–4 when recruited to the fisheries (ICES, 2021b). This is also older than breams caught in Lake Peipsi and Pihkva (between Estonia and Russia) where age classes 4–8 dominate the catches (Danilov et al., 2020). The values of the suggested size indicators are around 45–50 cm (Table 3), which corresponds to an average age of around 20 years or older. Hence, 10% or more of the caught breams can be expected to be around 20 years or older, which is rare in fished bream stocks (Danilov et al., 2020). This indicates a recently low fishing pressure on breams and we assume that an increased fishing for cyprinids should result in a lowered value in size-based indicators and a lowered mean age in the catch.

It is unknown at what age, or length, in the Baltic Sea breams become mature. All 54 breams sampled in spring 2021, during the spawning migration, were sexually mature so we do not know when they mature, but around 5–6 years seems plausible. In lakes there can be considerable variation in age at maturation (3–10 years; Backiel and Zawisza, 1968; Kompowski, 1988; Lelek and Buhse, 1992; Neja and Kompowski, 2001; Adakbek et al., 2003; Zhang et al., 2017), and size at maturity tend to be around 20–25 cm (Sundblad et al., 2020). Thus, we find it likely that most breams in the catches in this study have had multiple opportunities for reproduction, but further analysis on maturation status of the breams is necessary.

Although based on relatively few aged breams, the length-at-age of breams from the Bothnian Bay is similar to what Lappalainen et al. (2019) found in the Archipalego Sea, as well as for some smaller (presumably) non-fished lakes in Sweden, where especially breams from eutrophic lakes seem to initially grow faster (Sundblad et al., 2020). We can hence not see any major difference in the growth trajectory of breams in the Bothnian Bay from other populations in other parts of the Baltic Sea or in Swedish lakes. The parameters in growth models, like estimates of maximum body size ($L_{inf}$) tend to be uncertain (Mion et al., 2021), but can respond significantly to increased fishing pressure (Mion et al., 2021) and should be monitored.

The estimated total instantaneous mortality was Z = 0.12, which is low comparable to many fished stocks (Beverton and Holt, 1959). This might make the age and size structure of breams sensitive to increased fishing pressure. However, in Finland (the Archipelago Sea) a substantial bream fishery of around 150 tonnes/year during 2012–2018 seems to have not impacted the size at age and total mortality of bream (Lappalainen et al., 2019), and in a Finnish lake bream grew faster after substantial removal (Rask et al., 2020), suggesting abundant populations and potential compensatory effects following the fishery.

### 4.5. Implications for fisheries and management

In this study we have not considered fishing costs (time, equipment, fuel), differences in quality (more than size), or loss of opportunity, i.e. fishing for other species, or any other economic aspects of the fishery. In interviews, fishers express satisfaction with the additional income that the cyprinid fishery brings. Although it did not generate a high income, investment-, time- and travel costs were considered low (Van Berlekom, 2023). The considerable both temporal and spatial variation in catches indicate that some sites and time periods are more suitable than others for fishing for cyprinids. To distribute the main catches over a larger spatial area may still be advisable to avoid local overfishing as we expect that bream has a small-scaled population structure with many spawning aggregations.

Although bycatch in the gears evaluated in this study were low, a substantial increase in cyprinid fisheries may impact non-target species (if landed). Salmon, trout and whitefish seem not to be of major concern in the sites and time periods considered here, but perch and pike were main bycatch species, and in central parts of the Baltic Sea bycatch of pikeperch can be expected. In the Bothnian Bay, in contrast to some other areas of the Baltic Sea, there has not been any decline of perch (HELCOM, 2018) or pike (Olsson et al., 2023). If landed to a high degree, pike and perch could nevertheless be negatively impacted by a substantially increased bream fisheries both in the Bothnian Bay and elsewhere.

Bream fisheries in spring is likely to impact bream stocks more as it coincides with spawning. It is currently unknown to what degree these stocks are recruitment limited and how recruitment relate to stock size. Allowing fish to spawn is, however, usually wise to maintain sustainable catch levels (Froese, 2004).

The rapid increase in bream fisheries in both Sweden (this study) and Finland (Lappalainen et al., 2019), motivate assessments of the sustainability of the fishery, and if needed to take management actions. Bream fisheries are currently unregulated in Sweden, although there are gear restrictions for protecting salmon and eel. The indicators of sustainable use as presented in this study might be useful to follow and use if the bream fishery is continued and intensified. The monitoring of the indicators could either be part of self-management plans (e.g. for 'labelling' products as sustainable) or in national or regional management plans by governmental bodies. In this study, we have mainly used fishery dependent data. Fisheries independent monitoring programs aiming at other parts of the coastal fish community could also serve as a complement data source to the stock indicators presented in this study.

We here assume that the indicator values obtained reflects some type of 'non-fished' conditions as historic catches of the species have been minimal and the age distribution of the targeted stocks includes ages of fish rarely seen in fished stocks. Yet, we cannot suggest management target values for these indicators as these will also be dependent on specific management goals, such as maximum sustainable yield or natural-like age and size distributions. High cyprinid abundance is also associated with deteriorated habitat quality (HELCOM, 2018), and reductions in cyprinid abundances have been a mean to improve water quality in lakes ('biomanipulations'), with variable success (reviewed in Bernes et al., 2015), although results from marine areas are almost absent. Although bream may not constitute an important prey, access of cyprinids like roach can be important for the recovery of piscivorous fish. As a result, management target levels will differ depending on the management goal. To develop reference values for the suggested abundance and size indicators for different management goals should therefore be prioritised.

This study is based on data from coastal areas in the Bothnian Bay, and to what degree results are applicable to other areas, or other cyprinid species, is unknown. As the small-scale fisheries diversify by developing a cyprinid fishery in the coastal areas of the Baltic Sea, we however, believe stock indicators (median CPUE, $L_{90}$, $L_{max}$) could be applied also for other areas and species. To implement and assess the status of indicators and develop management targets can in the future aid evaluating the sustainability in these new fisheries.

## Ethical statement

The study involves data on vertebrate animals but all catching and killing of fish was done by commercial fishers and we only report data from logbooks, and does not require any ethical permit according to Swedish laws. In the camera study no fish was trapped or affected by the study and thereby no ethical permit was necessary.

## CRediT authorship contribution statement

ÖÖ, GS and JO conceived the ideas and designed methodology; ÖÖ, SL, ID, and RS collected and compiled the data; PL constructed the under-water camera system and helped with image analysis; MB and MK aged the breams; ÖÖ, SL and RS analysed the data; ÖÖ led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

## Declaration of Competing Interest

This work has been done in collaboration with commercial fishing companies but authors have no financial or other interest in the business, and have acted independently from fishing companies. This has been arranged by the NGO 'Race For The Baltic' that has arranged contracts with fishing companies to provide SLU with catch data.

## Data Availability

Catch, length and age data is available at https://github.com/orjost873/CyprFish. Video recordings are available upon request from the corresponding author.

## Acknowledgements

This work is the result of the collaboration between small-scale fishers in the area, the NGO 'Race For The Baltic' and the Swedish University of Agricultural Sciences (SLU). We want to thank all fishers and Race For The Baltic for their effort to provide us catch and size data. The County Board of Norrbotten have assisted with permits for the camera study. This work has been financed by Formas grant #2021-02666 and SLU collaboration grants to ÖÖ, the Swedish Agency for Marine and Water Management Dnr 2678-2000, and the Swedish Board of Agriculture Dnr 3.3.11-03109/2020 via the European Maritime, Fisheries and Aquaculture Fund.

## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.fishres.2023.106829.

## References

Adakbek, K.J., Liu, J., Chen, Q.Y., 2003. Studies on the biology and exploitation of Abramis brama Berg in the Ulungur Lake. J. Shanghai Fish. Univ. 12, 366–370.

Backiel, T., Zawisza, J., 1968. Synopsis of biological data on the bream Abramis brama (Linnaeus, 1758). FAO Fisheries Synopsis, 36. https://www.fao.org/3/a-69608e.pdf.

Bates, D., Maechler, M., Bolker, B., Walker, S., 2015. Fitting linear mixed-effects models using lme4. J. Stat. Softw. 67, 1–48. https://doi.org/10.18637/jss.v067.i01.

Bergenius, M., Ringdahl, K., Sundelöf, A., Carlshamre, S., Wennhage, H., Valentinsson, D., 2018. Atlas över svenskt kust- och havsfiske 2003-2015. Aqua Reports 2018:3. Institutionen för akvatiska resurser. Sver. Lantbr. https://res.slu.se/id/publ/94302.

Bernes, C., Carpenter, S.R., Gårdmark, A., Larsson, P., Persson, L., Skov, C., Speed, J.D. M., Van Donk, E., 2015. What is the influence of a reduction of planktivorous and benthivorous fish on water quality in temperate eutrophic lakes? A systematic review. Environ. Evid. 4, 1–28. https://doi.org/10.1186/s13750-015-0032-9.

Beverton, R.J.H., Holt, S.J., 1959. A review of the lifespans and mortality rates of fish in nature, and their relation to growth and other physiological characteristics. In: Wolstenholme, G.E.W., G.E.W., M., O'Connor, M. (Eds.), CIBA Foundation colloquia on ageing: the lifespan of animals, Volume 5. J & A Churchill Ltd, London, pp. 142–180.

Bnińska, M., 1991. Fisheries. In: Winfield, I.J., Nelson, J.S. (Eds.), Cyprinid Fishes. Fish & Fisheries Series 3. Springer, Dordrecht. https://doi.org/10.1007/978-94-011-3092-9_21.

Bonow, M., Svanberg, I., 2013. Karpfiskarnas tillbakagång i svenskt kosthåll. In: Från matproduktion till gastronomi, COMREC Studies in Environment and Development. Huddinge: Södertörns högskola, pp.91–114.

Boström, M.K., Östman, Ö., Bergenius, M.A., Lunneryd, S.G., 2012. Cormorant diet in relation to temporal changes in fish communities. ICES J. Mar. Sci. 69, 175–183. https://doi.org/10.1093/icesjms/fss002.

Danilov, M.B., Kriksunov, E.A., Bobyrev, A.E., Sheremet'ev, A.D., Mel'nik, M.M., Severin, S.O., Vasilev, P.V., Chistov, S.V., 2020. Population dynamics of the bream *Abramis brama* in Lake Peipus. J. Ichthyol. 60, 593–607. https://doi.org/10.1134/S0032945220040049.

Demandt, M.H., Bergek, S., 2009. Identification of cyprinid hybrids by using geometric morphometrics and microsatellites. J. Appl. Ichthyol. 25, 695–701. https://doi.org/10.1111/j.1439-0426.2009.01329.x.

EU, 2014. European Maritime and Fisheries Fund - Operational Programme for Sweden. European commission C(2018)8326.

Fitzgerald, C.J., Delanty, K., Shephard, S., 2018. Inland fish stock assessment: applying data-poor methods from marine systems. Fish. Manag. Ecol. 25, 240–252. https://doi.org/10.1111/fme.12284.

Fraser, D.I., Weinstein, H.M., Dyer, W.J., 1965. Post-mortem glycolytic and associated changes in the muscle of trap-and trawl-caught cod. J. Fish. Board Can. 22, 83–100. https://doi.org/10.1139/f65-008.

Friard, O., Gamba, M., 2016. BORIS: a free, versatile open-source event-logging software for video/audio coding and live observations. Methods Ecol. Evol. 7, 1325–1330. https://doi.org/10.1111/2041-210X.12584.

Froese, R., 2004. Keep it simple: three indicators to deal with overfishing. Fish Fish. 5, 86–91. https://doi.org/10.1111/j.1467-2979.2004.00144.x.

Greenstreet, S.P.R., Rogers, S.I., Rice, J.C., Piet, G.J., Guirey, E.J., Fraser, H.M., Fryer, R. J., 2011. Development of the EcoQO for fish communities in the North Sea. ICES J. Mar. Sci. 68, 1–11. https://doi.org/10.1093/icesjms/fsq156.

Hattula, T., Luoma, T., Kostiainen, R., Poutanen, J., Kallio, M., Suuronen, P., 1995. Effects of catching method on different quality parameters of Baltic herring (*Clupea harengus* L.). Fish. Res 23, 209–221. https://doi.org/10.1016/0165-7836(94)00358-4.

HELCOM, 2018. Status of coastal fish communities in the Baltic Sea during 2011-2016 — the third thematic assessment. Balt. Sea Environ. Proc. 161 https://Helcom.fi/wp-content/uploads/2018/11/BSEP161.pdf.

HELCOM, 2021. Climate Change in the Baltic Sea. Balt.ic Sea Environ.ment Proc.eedings 180. HELCOM/Baltic Earth. Baltic-Sea-Climate-Change-Fact-Sheet-2021.pdf.

ICES, 2021a. Baltic Salmon and Trout Assessment Working Group (WGBAST). ICES Sci. Rep. https://doi.org/10.17895/ices.pub.7925.

ICES, 2020b. Baltic Fisheries Assessment Working Group (WGBFAS). ICES Sci. Rep. 2, 45. 643 pp. http://doi.org/10.17895/ices.pub.6024.

ICES, 2020a. ICES Fisheries Overviews Baltic Sea ecoregion. Available at: https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2020/2020/FisheriesOverviews_BalticSea_2020.pdf [Visited 2021–05-19].

ICES, 2021b. Atlantic salmon (*Salmo salar*) in subdivisions 22–31 (Baltic Sea, excluding the Gulf of Finland). ICES Advice on fishing opportunities, catch, and effort Baltic Sea ecoregion. DOI: https://doi.org/10.17895/ices.advice.7848.

Jacobson, P., Bergström, U., Eklöf, J.S., 2019. Size-dependent diet composition and feeding of Eurasian perch (*Perca fluviatilis*) and northern pike (*Esox lucius*) in the Baltic Sea. Boreal Environ. Res. 24, 137–153. ⟨https://res.slu.se/id/publ/102238⟩.

Kell, L.T., Minto, C., Gerritsen, H.D., 2022. Evaluation of the skill of length-based indicators to identify stock status and trends. ICES J. Mar. Sci. 79, 1202–1216.

Kompowski, A., 1988. Growth rate of bream, *Abramis brama* (L., 1758), in lake Dabie and the Szczecin lagoon. Acta Ichthyol. Piscat. 18, 35–48. ⟨http://www.ejpau.media.pl/volume1/issue1/fisheries/art-03.html⟩.

Kuznetsova, A., Brockhoff, P.B., Christensen, R.H.B., 2017. lmerTest package: tests in linear mixed effects models. J. Stat. Softw. 82, 1–26. https://doi.org/10.18637/jss.v082.i13.

Lappalainen, A., Heikinheimo, O., Raitaniemi, J., Puura, L., 2019. Tehostetun pyynnin vaikutuksista Saaristomeren lahna- ja särkikantoihin. Luonnonvara- ja biotalouden tutkimus 74/2019. Luonnonvarakeskus. Helsinki. 21 s.

Lelek, A., Buhse, G., 1992. Fische des Rheins: — früher und heute —. Springer-Verlag, Berlin Heidelberg. https://doi.org/10.1007/978-3-662-06645-4.

Lundin, M., Calamnius, L., Hillström, L., Lunneryd, S.G., 2011. Size selection of herring (*Clupea harengus membras*) in a pontoon trap equipped with a rigid grid. Fish. Res. 108, 81–87. https://doi.org/10.1016/j.fishres.2010.12.001.

Miethe, T., Reecht, Y., Dobby, H., 2019. Reference points for the length-based indicator Lmax5% for use in the assessment of data-limited stocks. ICES J. Mar. Sci. 76, 2125–2139. https://doi.org/10.1093/icesjms/fsz158.

Mion, M., Haase, S., Hemmer-Hansen, J., et al., 2021. Multidecadal changes in fish growth rates estimated from tagging data: A case study from the Eastern Baltic cod (Gadus morhua, Gadidae). Fish Fish. 22, 413–427. https://doi.org/10.1111/faf.12527.

Naddafi, R., Olsson, J., 2018. Spatial and temporal variations in the bycatch of whitefish as well as catch species composition in vendace pair-trawls during 1973–2003. SLU ID: SLU.aqua.2018.5.1–34, SLU Aquatic resources, Öregrund.

Neja, Z., Kompowski, A., 2001. Some data on the biology of common bream, *Abramis brama* (L., 1758), from the Miedzyodrze waters. Acta Ichthyol. Piscat. 31, 3–25. https://doi.org/10.3750/AIP2001.31.1.01.

Nelson, G.A., 2021. fishmethods: fishery science methods and models. R. Package Version 1, 11–12. ⟨https://CRAN.R-project.org/package=fishmethods⟩.

Ogle, D.H., Doll, J.C., Wheeler, P., Dinno, A., 2022. FSA: Fisheries Stock Analysis. R package version 0.9.3, ⟨https://github.com/fishR-Core-Team/FSA⟩.

Olsson, J., 2019. Past and current trends of coastal predatory fish in the Baltic Sea with a focus on perch, pike, and pikeperch. Fishes 4, 7. https://doi.org/10.3390/fishes4010007.

Olsson, J., Bergström, L., Gårdmark, A., 2012. Abiotic drivers of coastal fish community change during four decades in the Baltic Sea. ICES J. Mar. Sci. 69, 961–970. https://doi.org/10.1093/icesjms/fss072.

Olsson, J., Andersson, M.L., Bergström, U., Arlinghaus, R., Audzijonyte, A., Berg, S., Östman, Ö., 2023. A pan-Baltic assessment of temporal trends in coastal pike populations. Fish.Res. 260, 106594 https://doi.org/10.1016/j.fishres.2022.106594.

Östman, Ö., Lingman, A., Bergström, L., Olsson, J., 2017. Temporal development and spatial scale of coastal fish indicators in reference ecosystems: hydroclimate and anthropogenic drivers. J. Appl. Ecol. 54, 557–566. https://doi.org/10.1111/1365-2664.12719.

Pitts, C.S., Jordan, D.R., Cowx, I.G., Jones, N.V., 1997. Controlled breeding studies to verify the identity of roach and common bream hybrids from a natural population. J. Fish. Biol. 51, 686–696. https://doi.org/10.1111/j.1095-8649.1997.tb01991.x.

R Core Team, 2021. R: A language and environment for statistical computing. R Foundation for statistical computing, Vienna, Austria. URL ⟨https://www.R-project.org/⟩.

Schreiber, H., Filipsson, O., Appelberg, M., 2003. Fisk och fiske i svenska insjöar 1860–1911. Finfo: 2003:1. Fiskeriverket, Göteborg.

Shephard, S., Reid, D.G., Greenstreet, S.P.R., 2011. Interpreting the large fish indicator for the celtic sea. ICES J. Mar. Sci. 68, 1963–1972. https://doi.org/10.1093/icesjms/fsr114.

Shin, Y.J., Rochet, M.J., Jennings, S., Field, J.G., Gislason, H., 2005. Using size-based indicators to evaluate the ecosystem effects of fishing. ICES J. Mar. Sci. 62, 384–396. https://doi.org/10.1016/j.icesjms.2005.01.004.

SLU, 2012. Metodhandbok för åldersbestämning av fisk. Institutionen för akvatiska resurser, SLU. Available at: ⟨https://www.slu.se/globalassets/ew/org/inst/aqua/externwebb/sotvattenslab/alderslaboratoriet/metodhandbok-alder-20120630.pdf⟩ [visited 2021–10-21].

Sundblad, G., Svensson, R., Östman, Ö., 2020. Hållbart nyttjande av lågt exploaterade fiskbestånd - ett pilotprojekt om ökat fiske på braxen. Aqua Reports 2020:14. Dept. Aquatic resources, Institutionen för akvatiska resurser, Sveriges lantbruksuniversitetSwedish University of Agricultural Scineces. 65 p. https://res.slu.se/id/publ/108939.

Svärdson, G., 1965. Braxen. (13–27). Drottningholm, Sweden.

Svensson, R., 2021. Development of northern pike (*Esox lucius*) populations in the Baltic Sea, and potential effects of grey seal (*Halichoerus grypus*) predation. Master thesis, A2E. SLU, Dept. Aquatic resources, Öregrund. ⟨http://urn.kb.se/resolve?urn=urn:nbn:se:slu:epsilon-s-16455⟩.

Swedish Government, 2016. En livsmedelsstrategi för Sverige – fler jobb och hållbar tillväxt i hela landet. Regeringens proposition 2016/17:104 [In Swedish].

Treer, T., Opačak, A., Aničić, I., Safner, R., Piria, M., Odak, T., 2003. Growth of bream, *Abramis brama*, in the Croatian section of the Danube. Czech J. Anim. Sci. 48, 251–256.

Tuomisto, J.T., Asikainen, A., Meriläinen, P., Haapasaari, P., 2020. Health effects of nutrients and environmental pollutants in Baltic herring and salmon: a quantitative benefit-risk assessment. BMC Public Health 20, 1–18. https://doi.org/10.1186/s12889-019-8094-1.

Valoukas, V.A., Economidis, P.S., 1996. Growth, population composition and reproduction of Bream *Abramis brama* (L.) in Lake Volvi, Macedonia, Greece. Ecol. Freshw. Fish. 5, 108–115. https://doi.org/10.1111/j.1600-0633.1996.tb00042.x.

Van Berlekom, P.A., 2023. A catch-22 scenario in the Swedish food system: A scientific examination of cyprinid fishing and its management possibilities in Sweden. Master thesis, A2E. SLU, Dept. Molecular sciences, Uppsala. ⟨http://urn.kb.se/resolve?urn=urn:nbn:se:slu:epsilon-s-18682⟩.

Waldo, S., Lovén, I., 2019. Värden i svenskt yrkesfiske. AgriFood Economics Centre Rapport 2019:1, Lund, Sweden.

Zhang, Z., Liu, C., Ding, H., Xie, P., Ma, X., Guo, Y., Xie, C., 2017. Reproductive biology of bream *Abramis brama* (L.) in the lower reaches of the Irtysh River. China Chin. J. Oceanol. Limnol. 35, 1471–1481. https://doi.org/10.1007/s00343-017-0198-9.