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Collaborative research enhances selectivity in a lake fishery

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Abstract

Size and species selectivity are crucial for developing sustainable fisheries. Our objective was to estimate the selectivity of whitefish fisheries in a large European lake through a collaboration of fishers, regional managers, and scientists. Fishers were given special permits to test, within a common framework and together with scientists, selectivity enhancement strategies adapted to their own experiences. Fishers and scientists jointly tested gillnets and pontoon traps and how fishing depth, soak time, fishing season, and mesh size were affected by bycatches of undersized fish of sensitive species. Results indicated that the selectivity of the fishery could be increased, particularly by targeting whitefish adjacent to spawning sites where spatiotemporal overlap with bycatch species was lower. Proposed changes to the fishery, such as new gear, would be costly initially but could become profitable over time due to a lower cost of handling bycatch. Our findings demonstrated that co-constructed knowledge can contribute to the governance of aquatic resources.

KEYWORDS
bycatch mitigation, gear selectivity, lake fisheries, participatory research, whitefish

1 | INTRODUCTION

Participatory research engages stakeholders and policymakers in the scientific process and emphasizes partnership, dialog, and collective learning (Frid, 2005; Wilson et al., 2003). Participatory fisheries research has been heralded as a means to bridge the gap between stakeholders, managers, and scientists to facilitate better governance of aquatic resources and the long-term profitability of small-scale fisheries (Mackinson et al., 2011). Particularly for small-scale fisheries, interactions with other sectors toward participatory management and governance have been suggested as an important success factor (Hilborn, 2007). Historically, fishers have interacted with scientists within the field of gear development and more recently in the development of more selective fishing strategies (Feekings et al., 2019; Kennelly & Broadhurst, 2002). Avoiding bycatch and associated discard mortality by enhancing selectivity is crucial for fisheries, particularly for mixed fisheries, and is often one of the most suitable problems to undertake in collaboration with fishers (Hall & Mainprize, 2005; Millar & Fryer, 1999). Controlling fishing mortality on nontarget sizes and species is important for an ecosystem approach to fisheries management (FAO, 2003; Fischer et al., 2015). Selectivity of fisheries can be improved by (i) adjusting efforts to prevent spatial and temporal overlap between target and nontarget species, (ii) modifying technical properties of fishing gear, and (iii) exchanging or upgrading to new fishing gears (Hall, 1996; Johnson et al., 2004). Negative effects of bycatch, despite increased selectivity, can be decreased by actions that enhance survival of discarded bycatch after release. In small-scale fisheries, particularly

†Died during the course of completing the study.

lake fisheries, detailed information needed to improve selectivity is often lacking (Fischer et al., 2015). One solution to obtain such data are to commission expertise and involve fishers in fishing operations for research (Johnson et al., 2004; Kraan et al., 2013).

In Lake Vättern, Sweden, the sixth largest lake in Europe and fourth largest in the EU, small-scale fisheries are governed by regional and national authorities. An advisory fisheries co-management group suggested potential collaboratory research involving fisheries stakeholders to solve urgent management problems, collaboratively test new methods, and compare and combine fisher and researcher knowledge to produce a more integrated assessment of the ecology and status of fish resources and exploitation patterns. After a referendum among stakeholders, a study was selected that focussed on the traditional gillnet fishery of whitefish (*Coregonus lavaretus*, L.) and Arctic char (*Salvelinus salvelinus*, L.). The fishery was historically very important but has recently been almost entirely replaced with a fishery for introduced signal crayfish (*Pacifastacus leniusculus*, L.), which rapidly became the most economically important species in fisheries in the lake. A combination of the switch to a new species (signal crayfish) and deteriorated stock status of the traditional target species, particularly Arctic char, led to steadily declining commercial gillnet effort and catch since the mid-70s. A suite of significant management efforts, including increased minimum size, gear restrictions, protected areas, and seasonal bans, helped to reverse the downward trend in stock status for many fish species in the lake in recent years (Sandström et al., 2017), but also made it very difficult for commercial fishers to target whitefish, which was formerly very important for the economy of the fishery but is not presently vulnerable. Arctic char and whitefish are currently exploited in a mixed gillnet fishery, so an increased fishery of the more abundant, but underexploited, whitefish (SLU Fiskbarometern, 2023) must be balanced against the protection of the more vulnerable Arctic char. Increasing the selectivity of fisheries for whitefish could offer commercial fisheries a more stable income to complement the harvest of signal crayfish. Crayfish fisheries are very profitable, with higher conversion margins than other small-scale freshwater fisheries in Sweden (Blomquist & Swahnberg, 2020). The main catch period, however, is restricted to a 2-month period from mid-July to mid-September, so crayfish fisheries could be combined with whitefish fisheries that are optimal during October–February, a period when crayfish fishing is negligible.

Our objective was to determine if (i) variation in selectivity, landings, and bycatch in a mixed-species lake fishery could be explained by easily measured variables; (ii) measures could be implemented to decrease bycatch of vulnerable species without seriously impairing the yield of target species. We collaborated with local fishers at all levels of research, including planning, study design, and interpretation of results. Population dynamics of introduced crayfish are often unstable, with a high proportion of Swedish populations collapsing in recent years (Sandström et al., 2014), so fishers should not rely solely on signal crayfish. Recreational fisheries for Arctic char and trout are extensive and contribute significantly to total catch (HaV & SCB, 2023). Whitefish catch, however, is currently negligible in recreational fisheries (HaV & SCB, 2023), so commercial whitefish catches could increase without conflicting with other stakeholders. A higher fishing mortality on whitefish could also lead to decreased intra-specific competition for common resources and thereby lead to faster growth through competitive release with other species that overlap in prey choice, such as Arctic char (Museth et al., 2007).

2 | MATERIALS AND METHODS

2.1 | Study area

Lake Vättern is a highly oligotrophic lake, 2–4 μg P L^{-1}, with a Secchi depth of 10–15 m. The drainage area (6300 km^2) is relatively small compared to the surface area (1893 km^2). Currently, 20 commercial fishers are licensed to fish in the common waters of Lake Vättern. Predominant gears are crayfish traps and gillnets. Following the expansion of introduced signal crayfish and decreased catches of native fish species, fisheries of Lake Vättern changed dramatically, starting in 2000. Commercial fisheries and an extensive recreational fishery mainly target Arctic char, brown trout (*Salmo trutta*, L.), and stocked Atlantic salmon (*Salmo salar*, L.).

2.2 | Data collection

Our approach was inspired by approaches summarized by Mackinson et al. (2015), Berkes et al. (2001), and Huntington (2000). To test the potential for improving the selectivity of the gillnet fishery, a general approach was discussed and agreed upon in workshops with fishers, scientists, and regional managers. Regional fisheries managers gave fishers permits for research fishing trips using fishing practices deviating from normal and thus not adhering to current regulations. All participating fishers followed a common design, but each fisher was allowed to make specific small adjustments to the sampling design in their fishing area without deviating from the common conceptual framework. Fishers discussed the design with scientists, adapted to their individual fishing areas, so that certain focal parameters varied among trials by individual participating fishers, including gillnet mesh size, gillnet height, and fishing depth (Table 1). Fishers often wanted to test a certain hypothesis, such as targeting whitefish during spawning or when aggregating to eat eggs of other spawning fish. Consequently, intervals of focal parameters were not the same for all fishers in all areas, but focal parameters varied (i.e., one fisher focused on testing different mesh sizes, while varying gillnet height and depth less). Fourteen fishers participated in data collection. Fishers in L. Vättern operated close to their homes and harbors, so fishing areas were scattered over most of the open basin (Figure 1). Trials lasted 5 years (2010–2014) and covered all parts of the season, although most fishing was in autumn and winter.

Fishers collected data collaboratively with scientists on 37% of survey trips using crews composed of both scientists and fishers, whereas data were collected by fishers only on the rest of survey trips in accordance with the agreed-upon survey design. Gillnets were fished at 563 different stations during 184 survey trips at 30 experimental

TABLE 1 Technical specifications of fishing gears used in joint fisher-research fishing with benthic gillnets and pontoon traps in Lake Vättern, Sweden, during 2010–2014.

Gillnets	Mean (min/max)
Mesh size (mm, bar mesh)	42,5 (35/50)
Height (feet)	10,5 (6/18)
Length (m)	294 (150/600)
Soak time (h)	68 (16/169)
Effort (m net per day)	836 (103/3050)
Fishing depth (m)	47 (1/116)
Lifting time	12:00 (07:00/19:00)
Pontoon traps	
Number of traps	2
Mesh size (mm)	20
Height of leading arm (m)	3.0
Length of leading arm (m)	125 (100/150)
Selection bars (mm)	50
Effort (days)	57
Fishing depth (m)	7.5 (7/8)
Days between lifting trap	6.7 (1/10)

sites. An experimental site was defined as the major fishing ground of an individual fisher with an average size of ~2×2km. Some fishers had more than one major fishing ground. The lake was divided into three main geographical fishing areas: southern, middle, and northern areas (Figure 1). At each gillnet station, the total catch in number and weight (g) of all species were recorded. All individual Arctic char and trout were measured in total length (mm). Total length and total weight of whitefish were measured for subsamples of at least 30 individuals per mesh size and field trip. All individual burbot were measured in total length (mm) and weight (g). Undersized Arctic char and brown trout were released. Particular emphasis was attributed to catches and size distributions of whitefish and undersized individuals of species categorized as unwanted and sensitive bycatch species, including Arctic char, brown trout, and burbot, because these three species were currently recovering from overfishing (SLU Fiskbarometern, 2023).

In addition to gillnets, the potential for use of pontoon traps was investigated to enhance selectivity of fisheries in shallow areas. Pontoon traps have never to our knowledge been used before in a lake. One small pontoon trap costs ~10,000 Euros. A pontoon trap is a passive fishing gear that is elevated to the surface using compressed air inflated into cushions attached to the top and bottom of the trap chamber (Hemmingsson et al., 2008). The pontoon trap was originally developed to reduce conflicts between salmon fishers and increasing numbers of gray seals in the Baltic Sea (Hemmingsson et al., 2008; Lunneryd et al., 2003). Fish are guided into the codend by a pivot arm in a larger section and then through a number of continuously smaller sections, into the cylindrical cod-end. Leading arms are 3m high and 100–150m long. The trap we used is one of the smallest on the market and was originally designed to mainly capture perch in coastal areas (Lundin, 2014). A single trap can easily be handled by a single fisher. Cod-end meshes were 0.5-mm Dyneema®

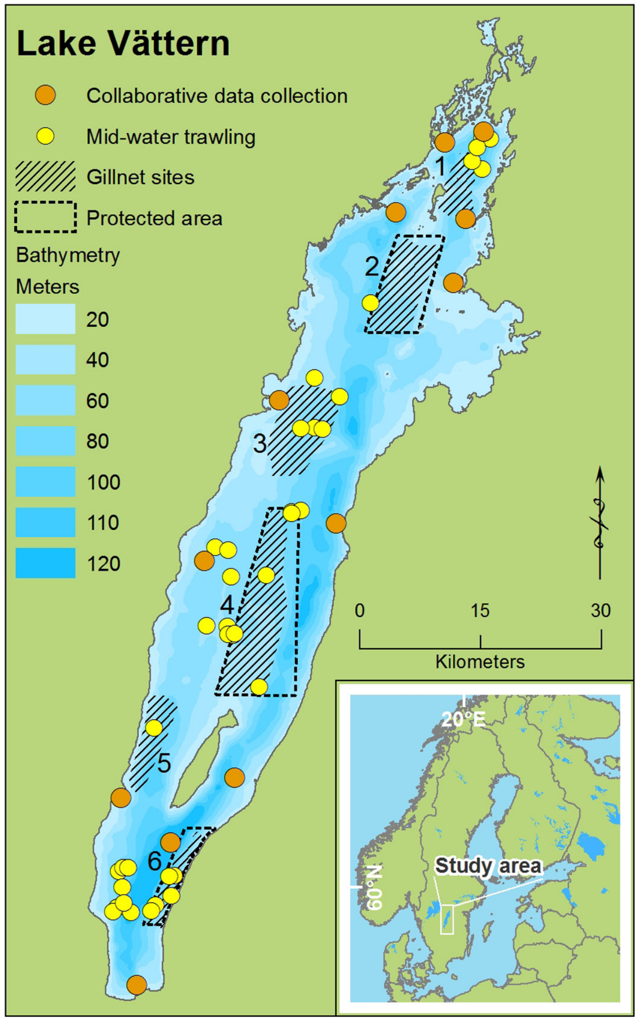


FIGURE 1 Bathymetry and locations of scientific surveys (dashed areas = multimesh gillnets, yellow dots = trawling sites), joint fisher-researcher surveys (brown dots = pontoon traps and gillnets), areas closed for fishing (dotted lines) in Lake Vättern, Sweden, during 2010–2014.

wire with a mesh size of 20mm. To further test selectivity of traps, a selection grid was assembled on one side of the fish house (Figure 2 and Table 1) to allow small fish to escape. Selection bars were covered with a Dyneema® net every second time the trap was emptied, to compare a "no-escape" control for half of fishing occasions with a selection bar to the other half without a selection bar. Pontoon traps were tested at two localities in L. Vättern (Figure 1), both of which were known to be important spawning areas for whitefish (Svärdson, 1979). The experiment lasted from early October to early December each year. Pontoon traps were emptied, on average, every 6days, for 9 times per trap over the study period.

2.3 | Statistical analyses

Data from the joint survey was reviewed for obvious errors using length-weight and size-mesh plots. Explanatory variables were further explored by creating co-plots and scatter plots to assess their

FIGURE 2 The pontoon trap chamber (left) and selection bars (right) used in Lake Vättern, Sweden, during 2010–2014. Photo by F. Engdahl.

variation and whether different variables were correlated to each other or not. The results were analyzed using three main approaches:

2.3.1 | Gear-specific species and size selectivity

Mesh size selectivity of the fishery was compared to a gillnet monitoring program, using the SELECT approach (Millar & Fryer, 1999), as previously estimated for Arctic char (Jonsson et al., 2013). The same approach was used here to calculate selectivity for Arctic char, whitefish, burbot, and brown trout, based on data from the joint study and the gillnet monitoring program. The probability of catching a fish in a gillnet was separated into the probability of a fish: (1) encountering the net and (2) being caught and retained in the net. This approach normally starts with removing outliers that were not wedged and would otherwise bias size selectivity. However, our analysis focused on bycatch probability, so we did not remove outliers. Selectivity curves were fitted using normal, log-normal, asymmetric, and bimodal normal distributions. For each species and functional model type, model fit was maximized by searching for model parameters that produced the lowest model deviance. The model with the lowest mean model deviance was considered the best model for each species and was used as the selectivity curve for that species. The selectivity curve for a species depicted the retention probability of a gillnet and the lengths of fish in relation to mesh sizes (RL = relative length). The area under the selection curve shorter than the minimum legal length of brown trout, Arctic char, and burbot was used as a proxy for the likelihood of catching undersized fish in a specific mesh size.

2.3.2 | Selectivity and yield targets

Long-term selectivity and yield targets for a whitefish fishery were developed from commercial catch records of whitefish in Lake Vättern during 2010–2014. The yield of whitefish (kg) per 1000 m of net per day was used for all fishing trips when whitefish were registered as the target species (usually, gillnets with 43-mm bar mesh). The median whitefish catch was used as a minimum target for what we considered a profitable catch level, here termed the "minimum viable commercial level" that was accepted by fishers as a target. Joint study catches above and below the minimum viable commercial level were noted as improvements and deteriorations, respectively. The maximum acceptable bycatch level of undersized Arctic char and brown trout was set using the lower 90% confidence interval of the average number of individuals shorter than the minimum legal size in standardized multimesh gill-net surveys in L.Vättern. Gillnet surveys have been annual since 2005 (except for 2013) using multi-mesh gillnets with meshes of 20–60 mm bar mesh in six different areas from late July to mid-August randomly distributed in available depth strata in all habitats deeper than 10 m (Jonsson et al., 2013). For the 4 years of the joint study (2010–2014), catches of undersized Arctic char and brown trout were summed per 1000 m gillnet per day in panels of 43-mm mesh, the mesh size used by commercial whitefish fisheries. A fish was considered undersized if it was shorter than the minimum legal length of 50 cm for Arctic char and brown trout. Whitefish, burbot, and the other fish species had no legal length limits. To evaluate the average rate of potential annual improvement for a new selectivity strategy, the proportion of fishing trips each year with bycatches over and under the maximum acceptable level (see above) respectively, were calculated.

2.3.3 | Explanatory variables for harvest and bycatch of target species

To evaluate the balance between the profitability of the whitefish fishery and the protection of sensitive species, potential explanatory factors were evaluated for both catch of whitefish and bycatch of other species. The following response variables were evaluated:

(i) Catch of whitefish = kg × (1000 m gillnet)$^{-1}$ × day^{-1},
(ii) Total bycatch of other species = number of non-whitefish × (1000 m gillnet)$^{-1}$ × day^{-1},
(iii) Species-specific bycatch ofsensitive species = number of undersized trout and Arctic char and all burbot × (1000 m gillnet)$^{-1}$ × day^{-1},
(iv) Bycatch ratio = number of undersized bycatch individuals (1000 m gillnet)$^{-1}$ × day^{-1}/kg whitefish × (1000 m gillnet)$^{-1}$ × day^{-1}, and
(v) Bycatch percentage = number of undersized bycatch individuals × (1000 m gillnet)$^{-1}$ × day^{-1}/number of whitefish + number of legal size bycatch species × (1000 m gillnet)$^{-1}$ × day^{-1}.

Hierarchical partitioning analysis (HPA) and Generalized Additive Models (GAM) were used to test how each response variable was related to predictor variables: (i) fishing season (month), (ii) gillnet mesh size, (iii) gillnet height, (iv) soak time, (v) fishing depth and (vi) fishing area (south, middle, or north). Hierarchical partitioning analysis used the program Jmp version 11.0 to identify groups of data that maximized the similarity of catch composition and the most important explanatory variables for splitting data into groups. Relationships between response and explanatory variables were tested using GAMs to relate catches and bycatches to environmental descriptors and gear characteristics. GAMs displayed how individual main effects influenced each response variable using smoothing splines, as semi-parametric extensions of generalized linear models, for fitting non-linear relationships without prior assumptions about the shape of the response (Wood, 2006). A Poisson distribution and log link function were used for all models. Models used the "mgcv" package for R (3.1.1), connected to Brodgars interface version 3.7.4 (Zuur et al., 2007). GAM performance and selection of the best available models used Aikake's Information Criterion (AIC).

3 | RESULTS

3.1 | Selectivity

The size distribution of whitefish in multi-mesh survey gillnets was slightly bimodal reflecting catches in the two smallest mesh sizes (20 and 30 mm), with peaks at 200–250 mm and 300–350 mm. This was unlike data from trawling with one less pronounced peak around 350 mm and pontoon traps with a pronounced peak at 380 mm (Figure 3). Size selectivity was normally distributed for whitefish, bimodal for Arctic char, and skew-normal for brown trout and burbot (Figure 4a; Table S1). In particular, selectivity for brown trout was much broader than for other species. Peak selectivity was lower for Whitefish (RL = 0.93), than for Arctic char (RL = 1.16), brown trout (RL = 1.28), and burbot (RL = 1.07; Figure 4, upper panel), which indicated that whitefish reach their maximum retention probability relative to mesh size at a smaller size than the other three species. The probability of catching undersized Arctic char, brown trout, and burbot increased as mesh size decreased (Figure 4, lower panel; Table S1).

3.2 | Gillnet catches

In the joint gillnet survey, 15 species were caught (Table 2). Whitefish was the predominant species (94% of all fish caught). Other common species were burbot, Arctic char, trout, vendace, perch, smelt, and signal crayfish. Most whitefish were caught at or near known spawning sites. In 60% of all fishing trips (339 of 563), no undersized Arctic char or brown trout were caught. On average, 1.4 undersized Arctic char or brown trout were caught per 1000 meters of net per day. Of all undersized fish caught, 75% were released alive.

Fishing area was the most important factor influencing whitefish catch in Lake Vättern, followed by fishing depth (Table S2). Catches were higher in the southern part of Lake Vättern than in the middle or northern parts, especially during late autumn and winter, and highest at depths exceeding 46 m. The optimal time of year for targeting whitefish was late fall and winter (Figure 5A$_{i}$; Table S3), optimal mesh sizes were 38–43 mm (Figure 5A$_{ii}$), and optimum depths were 80–110 m and 5–20 m (Figure 5A$_{v}$ Table S3). The optimum gillnet height was 10–12 feet (3.05–3.66 m), and shorter soak times resulted in higher catches (Figure 5A$_{iii,iv}$). Bycatch ratio and bycatch percentage were not useful for predicting whitefish catch, but depth was significantly related to bycatch ratio and bycatch percentage, with lower bycatches than whitefish catches at depths >30 m (Table S3).

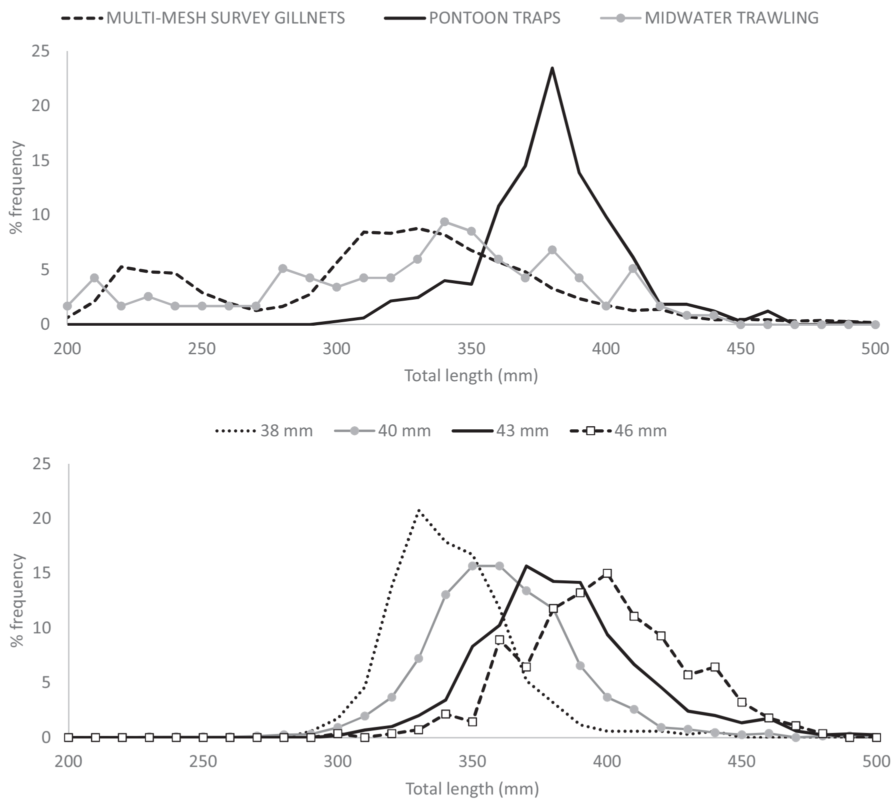


FIGURE 3 Total length (mm) of whitefish in the four most commonly used gillnet mesh sizes (bar mesh: 38, 40, 43, and 46 mm) in a joint fisher-research survey (upper panel), multimesh gillnets surveys (bar mesh = 20–60 mm), midwater trawling, and pontoon traps in Lake Vättern, Sweden, during 2010–2014.

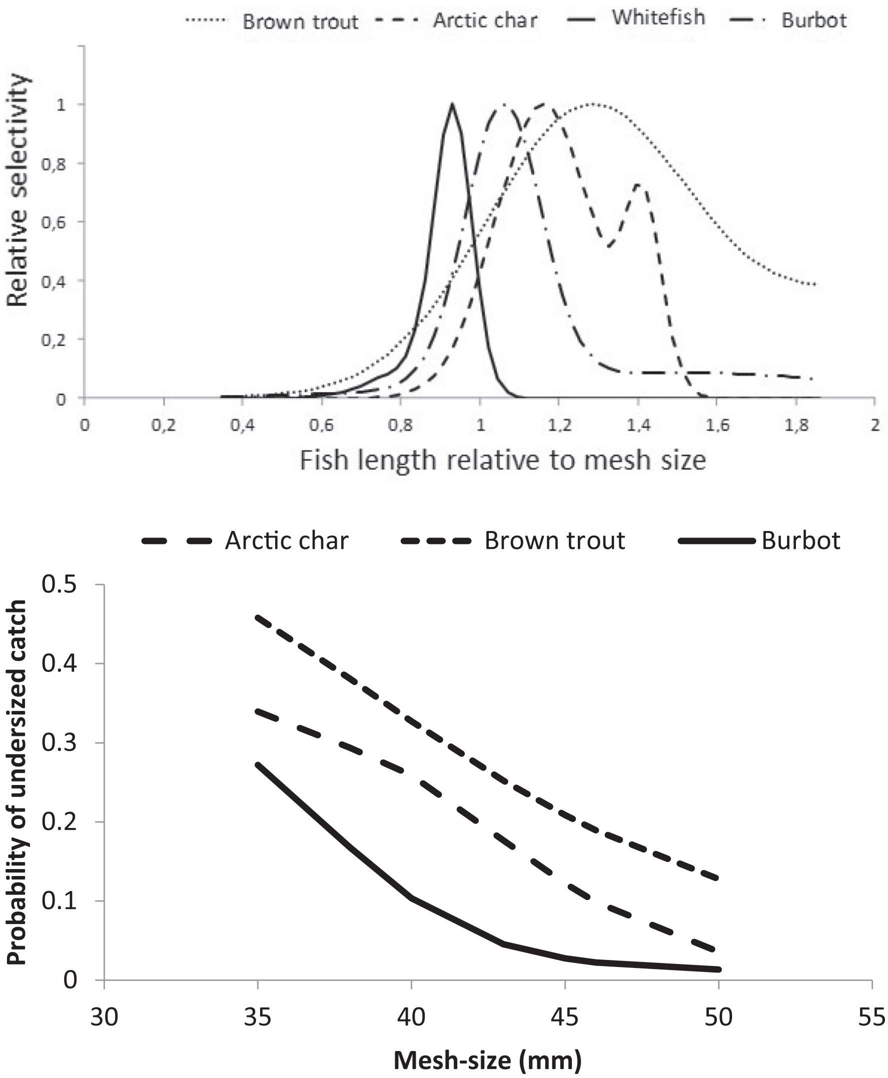


FIGURE 4 Relative selectivity of whitefish, Arctic char, brown trout, and burbot in gillnets versus the ratio of total length (cm) to mesh size (mm, bar mesh) (RL, upper panel), and probability of retention of undersized Arctic char, brown trout, and burbot versus mesh size (bar mesh) in Lake Vättern, Sweden, during 2010–2014.

Arctic char, brown trout, and burbot ranked 2–4 (by weight) behind whitefish in gillnet catches (Table 2). Arctic char was the third most common species in the catch, of which 32% were below the minimum size and 69% were released alive. Bycatch of undersized Arctic char was related to fishing area (lower in the north), mesh size (negative correlation), gillnet height (10–15 feet optimum), and soak time (negative correlation) (Figure 5B, Tables S2 and S3). Brown trout was the fourth most common species in the catch, of which 23% were below the minimum size and 70% were released alive. Bycatch of brown trout was related to fishing area (lower in the north), depth (higher in shallow areas), and fishing season (lower in late fall and winter) (Figure 5c; Tables S2 and S3). Burbot was the second most common species in the catch. Bycatch of burbot was related to fishing depth (higher in depths >37 m), season (highest in winter), and fishing depth (highest at 50–85 m depth) (Figure 5d; Tables S2 and S3).

3.3 | Pontoon traps

Catch of whitefish in pontoon traps was high at one site (630 or 11.0 kg per day) and low at the other site (3 or 0.05 kg per day). Besides whitefish, eight other fish species were caught, of which roach, Northern pike, and bream were most common (Table 2). The catch peaked during the spawning period (mid-October to mid-November) when whitefish migrated closer to shore on their way to spawning areas. All bycatch species were released alive. The average length of whitefish differed little between periods with (376.6 mm) and without (388.4 mm) the selection grid in place. Whitefish in the pontoon trap were predominantly sexually mature (350–420 mm), so differed greatly from the size distribution of whitefish in multi-mesh gillnets (Figure 3). Small-sized species, roach and ruffe, were not caught in the trials with a selection grid, likely because small-sized species swam through the grid.

3.4 | Selectivity and viability targets

The target for minimum viable fishing was 6.2 kg of whitefish per 1000 m net per day. The threshold for acceptable bycatch of undersized sensitive species was 2.1 fish per 1000 m net (Figure 6). The average catch of whitefish in all trips during the joint selectivity project (26.0 kg per 1000 m net) was well above the target level (Figure 6b). Of

TABLE 2 Species-specific catches in joint fisher-research fishing with benthic gillnets and pontoon traps in Lake Vättern, Sweden, during 2010–2014.

	Gillnets			Pontoon traps		
Species	Prevalence (%)	Number (N)	Weight (kg)	Prevalence (%)	Number (N)	Weight (kg)
Whitefish (*Coregonus* sp.)	94	27,646	11,330	56	1603	676
Burbot (*L. lota*)	73	4810	3083	6	2	3
Arctic char (*S. s alpinus*)	65	1671	1023	6	1	1.5
Brown trout (*S. trutta*)	33	373	437	0	0	0
Vendace (*C. alburnus*)	32	396	18	0	0	0
Perch (*P. fluviatilis*)	30	685	282	39	23	3.9
Smelt (*O. operlanus*)	30	6887	275	0	0	0
Signal crayfish (*P. leniusculus*)	28	359	18	6	3	0.3
Ruffe (*G. cernua*)	22	61	1	6	1	0.1
Roach (*R. rutilus*)	17	33	11	28	143	10
Four-horned sculpin (*M. quadricornus*)	12	404	4	0	0	0
Common bream (*A. brama*)	11	29	35	33	15	23
Northern pike (*E. lucius*)	11	36	102	39	14	71
Grayling (*T. thymallus*)	8	33	20	0	0	0
Salmon (*S. salar*)	1	4	4	0	0	0
Eel (*A. anguilla*)	0	0	0	6	1	1.5

30 experimental sites fished in the joint survey, 73% exceeded the target for viability and 73% were below the bycatch threshold (Figure 6c). For individual gill-net trial stations, 60% exceeded the target for viability and 80% were below the bycatch threshold. About half of individual gill-net stations (45%) and fishing areas (53%) were simultaneously higher than the target for viability and below the bycatch threshold. Catches of undersized fish (number per 1000 m nets/day) were significantly lower in the joint study than in similar mesh sizes in the scientific survey (Figure 6a), which suggests that fisher knowledge of locations and times significantly improved selectivity over nets that were distributed randomly. The proportion of trips with bycatches below the bycatch threshold increased over time, whereas the catch rate of undersized sensitive species in scientific surveys increased over time, which suggested that abundance increased over time (Figure 6). Most areas with catches above the target for viability and bycatch below the maximum acceptable level were in the southern part of the lake, adjacent to the deep north–south rift of Lake Vättern.

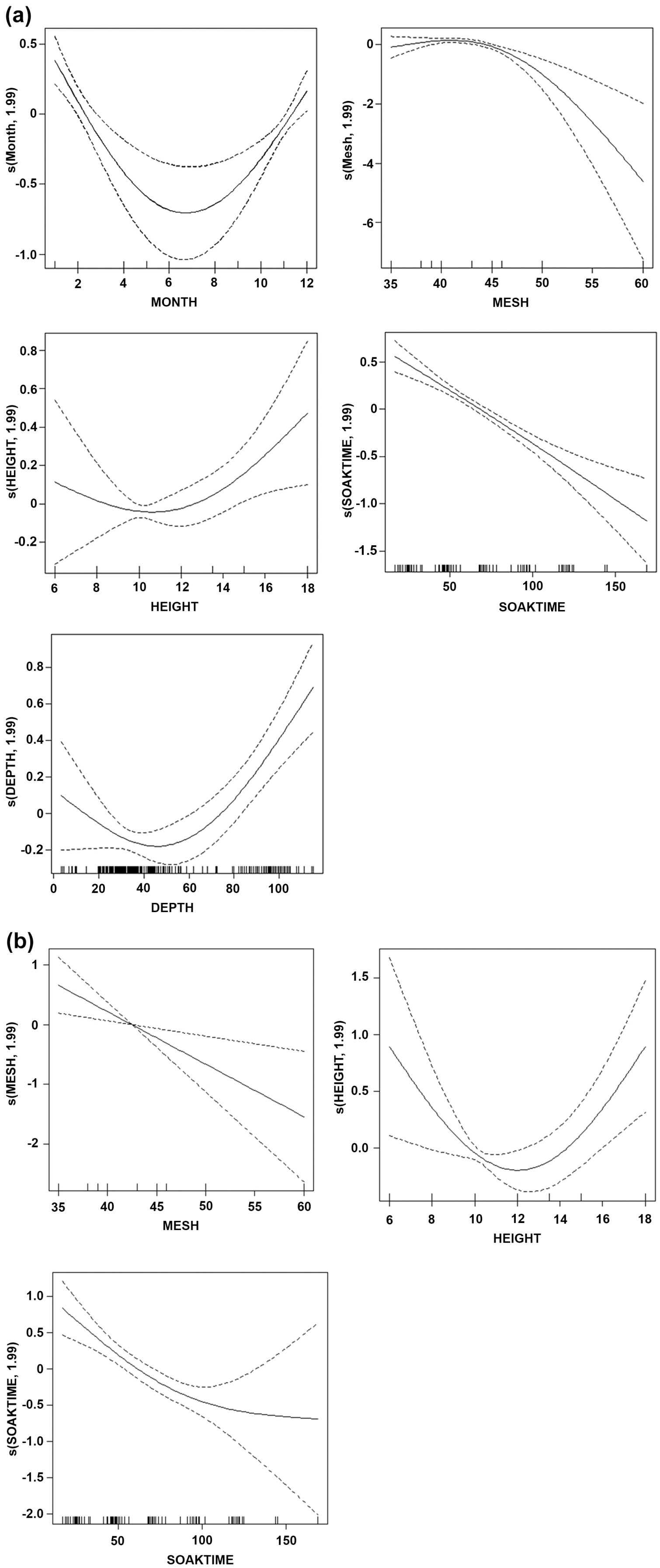
4 | DISCUSSION

We found that the selectivity of fisheries could likely be changed to reduce bycatch of sensitive species in Lake Vättern, Sweden, and thereby increasing sustainability of mixed fisheries that often suffer from bycatch of sensitive species (Hall & Mainprize, 2005). Similar to many other studies on bycatch mitigation we found that combining knowledge of fishers with scientific expertise in a collaborative setting could facilitate research and management solutions that reduce bycatch by changing how fisheries operated (Gilman et al., 2022; Northridge et al., 2011).

4.1 | Catch optimization and bycatch mitigation recommendations

When developing the selectivity of fisheries, there is a difficult trade-off between optimization of catch rates of the more productive target species of the fishery and avoidance of by-catch of sensitive species. This challenge is a common concern for many commercial whitefish fisheries in the Northern Hemisphere (Johnson et al., 2004; Kallio-Nyberg et al., 2018; Langseth & Cottrill, 2015).

One approach to enhance selectivity is to modify the technical properties of the existing fishing gear (Hall, 1996). In a gillnet fishery, this normally is dealt with by changing the restrictions as regards mesh sizes (Johnson et al., 2004). Gillnet selectivity is often taken into account when analyzing gillnet catch data (Radomski et al., 2020) and when assessing the status of stocks (Liljestrand et al., 2023). Similar to results from other studies (Johnson et al., 2004; Jonsson et al., 2013), mesh-related selectivity was an important factor for both catches of the focal species as well as the bycatch species in this study. The catch of whitefish was highest in a range of mesh sizes from 38to 43 mm and bycatch probability increased with reduced mesh size in all bycatch species. Although normally discussed and/or analyzed in relation to the length of the fish, gillnet selectivity is usually more closely related to girth (Jonsson et al., 2013; Millar & Fryer, 1999; Reis & Pawson, 1999) and thus selectivity can alter if fish condition changes. Several studies have shown that whitefish condition may change significantly over time as a response to several factors such as nutrient loading (deWeber et al., 2021; Rösch et al., 2018), competition from invasive species (Lumb et al., 2009; Rösch et al., 2018), and fisheries exploitation (Nusslé et al., 2009).


(a)
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(b)
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MESH
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SOAKTIME

FIGURE 5 (a) Partial response curves for generalized additive models (GAM) illustrating relative effects (positive or negative) of month, mesh size (bar mesh, mm), net height (feet), soak time (h), and fishing depth (m) on catch of whitefish (kg/1000 m net/day) in Lake Vättern, Sweden, during 2010–2014. Only significant predictors ($P < 0.05$) are shown. (b) Partial response curves for GAM illustrating relative effects (positive or negative) of mesh size (bar mesh, mm), net height (feet), and soak time (h) on bycatch of undersized Arctic char (number < 50 cm TL/1000 m net/day) in Lake Vättern, Sweden, during 2010–2014. Only significant predictors ($P < 0.05$) are shown. (c) Partial response curves for GAM illustrating relative effects (positive or negative) of month and fishing depth (m) on bycatch of undersized brown trout (number < 50 cm TL/1000 m net/day) in Lake Vättern, Sweden, during 2010–2014. Only significant predictors ($P < 0.05$) are shown. (d) Partial response curves for GAM illustrating relative effects (positive or negative) of month, mesh size (bar mesh, mm), net height (feet), soak time (h), and fishing depth (m) on bycatch of undersized burbot (number < 40 cm TL/1000 m net/day) in Lake Vättern, Sweden, during 2010–2014. Only significant predictors ($P < 0.05$) are shown.

Reoligotrophication is currently regarded as an important phenomenon leading to decreased condition, growth, and landings of whitefish (Anneville submitted manuscript, deWeber et al., 2021; Rösch et al., 2018), this could be particularly important in Lake Vättern since water phosphorous concentration has decreased significantly in recent years (Kao et al., 2020).

In lakes, where whitefish condition and growth has changed over time, management often respond by altering the legal mesh size (Müller et al., 2007). In L. Constance in Germany, Austria and Switzerland mesh size was first increased when whitefish growth and condition were favored due to eutrophication and later decreased as a response to ongoing reoligotrophication (deWeber et al., 2021; Gerdeaux et al., 2006). Fishing with smaller mesh sizes might maintain catches but as our study and several others show—lower mesh size often leads to higher by-catches (Langseth & Cottrill, 2015; Veneranta et al., 2017).

The shape of the selectivity curves of the individual species varied between species, indicating that the mode of catch may differ. Particularly, brown trout and Arctic char master curves were broader and more right-skewed than the master curve of whitefish. Participating fishermen attributed this to them being more prone to get entangled in teeth and mouth parts, a phenomenon also described in scientific literature and known to affect selectivity patterns (dos Santos et al., 2003; Hansen et al., 1997). In addition to mesh size both soak time and gillnet height affected catches. Gillnet height may also be related to the hanging ratio (the relationship between the length of the head or foot rope to the stretched length of the gillnet) which may affect selectivity by its influence on the slackness of the net (Hovgård & Lassen, 2000; Samaranyaka et al., 1997). The statistical evaluation of our experiment showed that the best height of the nets was 10–12 feet (3.05–3.66 m) for optimizing catch rates of whitefish and avoiding bycatches. Soak time was important for whitefish and burbot in our study and long soak time affected catch per unit of effort negatively. This is likely because gillnets get saturated over time (Marjomäki et al., 2015; Prchalová et al., 2011). Soak time, however, was less important for the bycatch of Arctic char and brown trout. Soak time is also an important factor due to its influence on survival at release. A shorter soak time normally leads to higher survival of released individuals (Bell & Lyle, 2016; Buchanan et al., 2002). Thus, a shorter soak time is recommended since it may facilitate higher catches of whitefish and potentially enhance the survival of released bycatch.

Another approach to enhance fisheries selectivity that has gained increased interest in recent years is to adjust efforts to try to reduce spatial and temporal overlap between the target and the nontarget species (Clay et al., 2019; Roe et al., 2014). If the temporal and spatial restrictions of the effort in gillnet fisheries are carefully regulated, bycatches could be hypothesized to decrease without drastically reducing catches of whitefish (Kallio-Nyberg et al., 2018). In our case, fishing area was the most important predictor of both whitefish catch rates and bycatch of sensitive species, indicating that restrictions as regards fishing area can be useful. Nevertheless, since bycatch and whitefish catch were highest in the same area, it is probably not sufficient to optimize both catch and bycatch targets. Langseth and Cottrill (2015) showed, based on fisher observer data, that bycatch of lake trout in whitefish fisheries could be avoided in shallow areas. Fishing depth was a significant predictor of whitefish catch also in our study, with the highest catches at depths over 80 m. Bycatch of trout was higher in shallow areas and of burbot in intermediately deep areas (40–60 m). To promote the whitefish fishery, while minimizing bycatch, whitefish could be targeted when they spawn in deep waters where bycatch is lowest. Whitefish catches were also relatively high in most shallow areas we sampled, but bycatch was also high in these areas, so we recommend that other gear, such as pontoon traps, be developed for fishing in shallow areas. One caveat with spatiotemporal restrictions is that if catches become lower due to bycatch mitigation regulations, fishers may respond by increasing their overall effort (Hall & Mainprize, 2005), thus potentially outweighing the positive effects of bycatch. Such a response, however, is less likely in Lake Vättern due to the fishery being effort-limited (there is a maximum number of gears set for each fisher). Spatio-temporal restrictions in fishing efforts may take advantage of the marked environmental gradients that often exist in large lakes (Håkanson, 2010), but assembling data on the distribution of several species over all fishing seasons is a challenging task. We believe that collaborative approaches can complement traditional monitoring programs to enable researchers and managers to adequately account for spatial and temporal patterns in ecosystem-based management of aquatic resources (Bryhn et al., 2021).

Certain results, for example, high catches of whitefish in shallow as well as deeper areas are likely because multiple ecotypes of whitefish are present in Lake Vättern (A. Sandström, E.Jansson, J. Dannewitz, S. Bergek, S. Palm, T. Prestegaard, and J. Norrgård, unpublished; Svärdson, 1979). Whitefish in large lakes are known to occur in multiple ecotypes differing in diet, habitat choice, and life history (Bernatchez et al., 2008; Harrod et al., 2010). Two distinct ecotypes of whitefish occupy different depths in Lake Vättern,

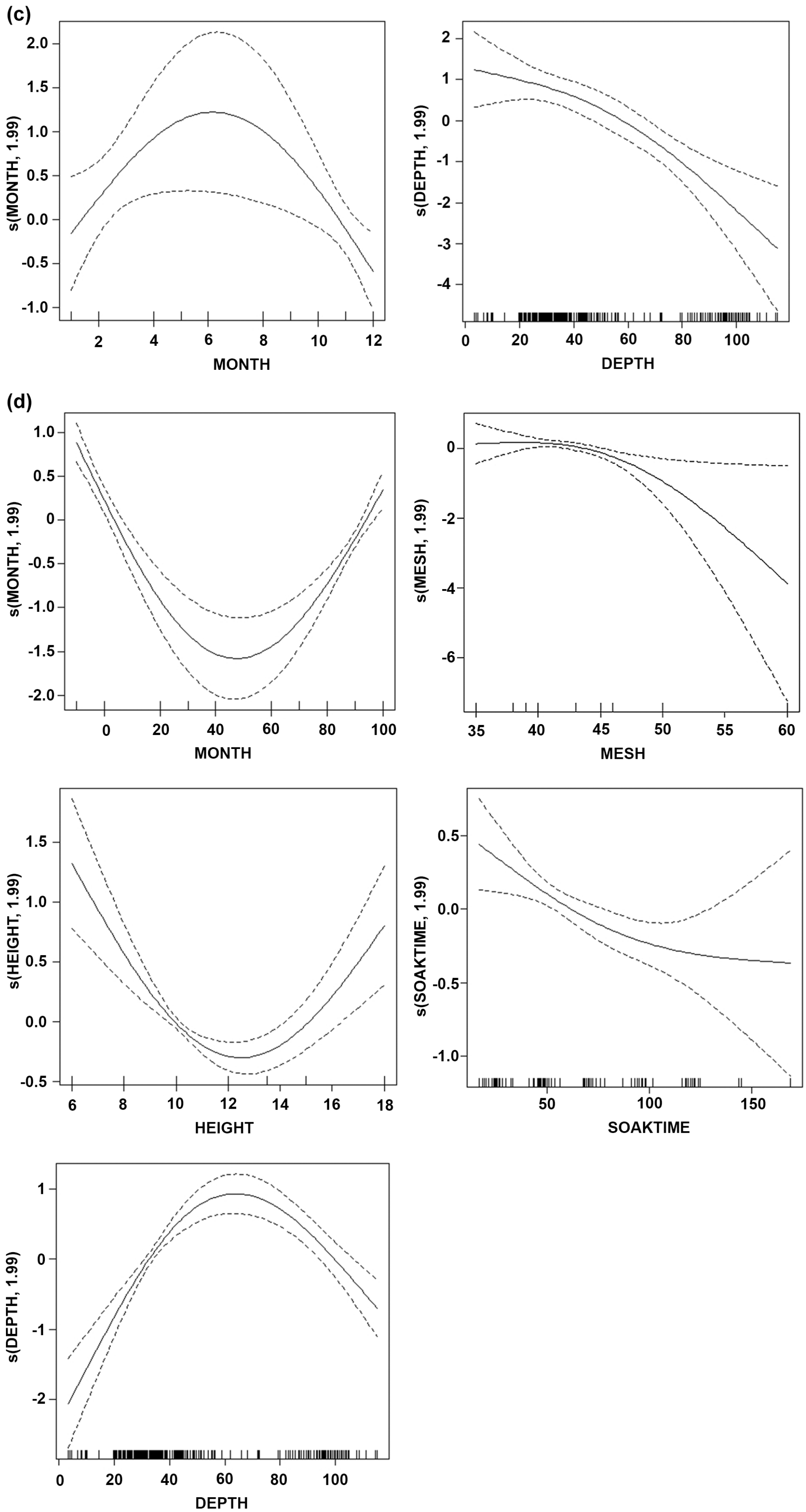

FIGURE 5 (Continued)

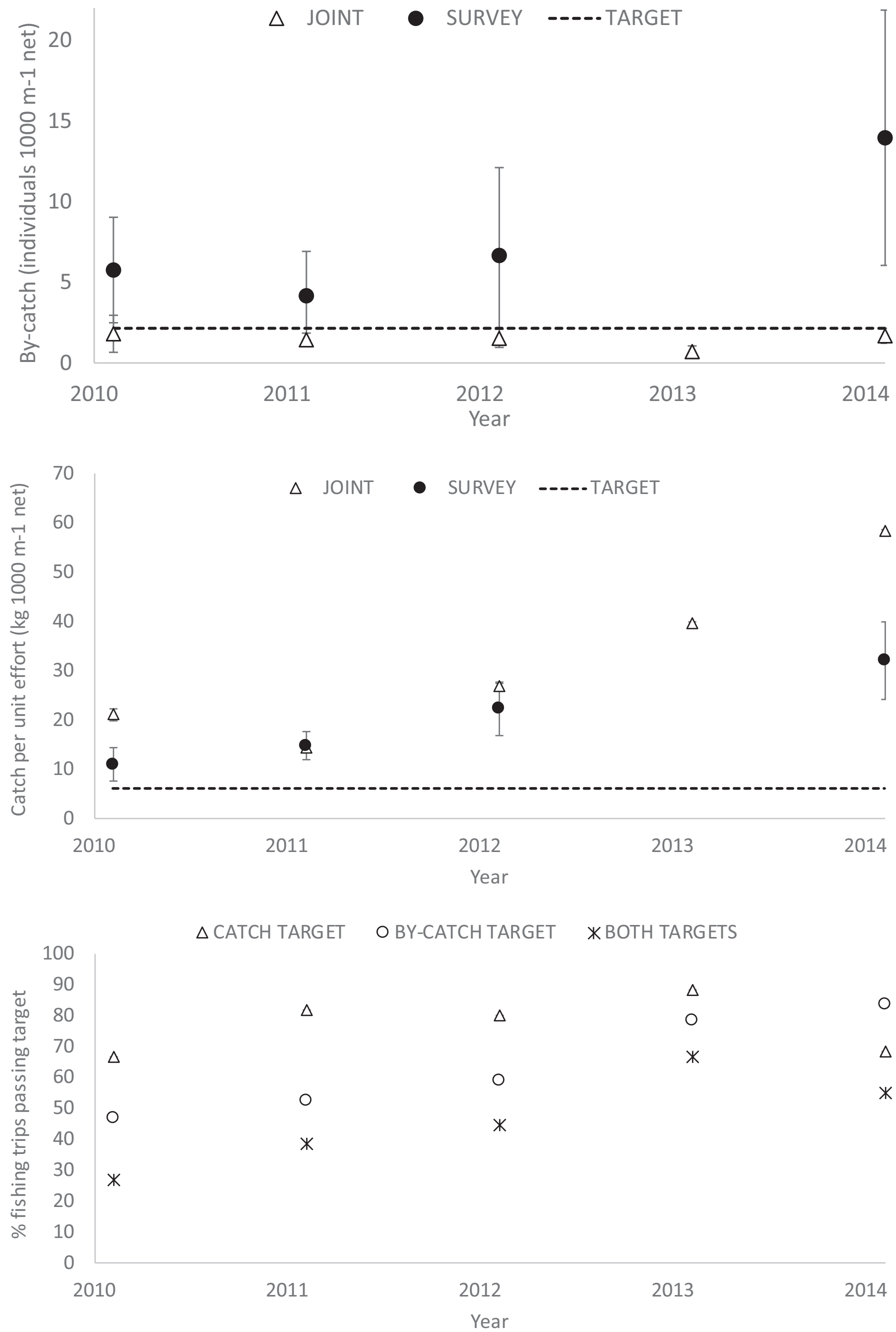

FIGURE 6 Mean annual bycatch/1000 m gillnet/day of undersized Arctic char and brown trout (±2 × SE; upper panel), catch per unit of effort per 1000 m net of whitefish (±2 × SE; middle panel) in joint fisher-scientist experimental trials, scientific surveys, and targets (43 mm bar mesh panel only, for reference), and percentage of fishing trips in joint fishers-scientist experimental trials with levels of bycatch under, over, and within both targets (lower panel) in Lake Vättern, Sweden, during 2010–2014.

including a river ecotype that spawns at one location in 1–2 m of water and a lesser sparsely rakered whitefish that spawns mainly in shallow areas but also at intermediate depths, both of which spawn from October to late November (A. Sandström, E.Jansson, J. Dannewitz, S. Bergek, S. Palm, T. Prestegaard, and J. Norrgård, unpublished; Svärdson, 1979). A third less distinct ecotype, deep-spawning lesser sparsely rakered whitefish, spawns in 80–120 m of water in December–early February (A. Sandström, E. Jansson, J. Dannewitz, S. Bergek, S. Palm, T. Prestegaard, and J. Norrgård, unpublished). Significant aggregations of whitefish in the southern deep rift have been observed in a scientific acoustic survey in winter (Sandström et al., 2016), thereby supporting the existence of a third ecotype that may explain high catch rates from early December to early February in our study. The conservation status of multiple whitefish ecotypes must also be considered, to ensure that all ecotypes and their genetic variability are managed sustainably.

4.2 | Pontoon traps

Selectivity of fisheries may also be improved by changing or upgrading to new fishing gear (Hall, 1996). Since it is hard to avoid bycatch in gillnets, traps of various kinds could provide an interesting alternative (Hemmingsson et al., 2008; Johnson et al., 2004). We also hoped that the use of pontoon traps could overcome problems with large catches of crayfish that often cause problems by destroying nets and eating fish in the catch. Crayfish are also very laborious to remove from gillnets. We conclude that pontoon traps could be used to complement other gears used in inland fisheries. Although we did not test larger traps designed for whitefish in coastal waters, we still caught nearly twice as many whitefish in one area (11 kg/day) than were caught in conventional gillnets (6 kg/day) on average in Lake Vättern during 2010–2014. Fishers appreciated the possibility of releasing bycatch manually or using a selection grid, and the ergonomic construction for emptying the traps using the air-filled pontoons. However, the trap was sensitive to very high catches and harsh weather conditions. Problems with high catches could potentially be remedied using a hose to collect fish instead of in a box inside the cylinder-shaped cod-end. We also believe that bigger, specialized traps for whitefish, could be used in deeper waters that would facilitate catching whitefish over a longer period of the year than a traditional trap. Last, the design of the selection grid could be modified with a different bar size and location to fit different species in different lakes (Lundin, 2014).

4.3 | Using collaborative approaches in small-scale fisheries research

Small-scale fisheries in general and European lake fisheries in particular share prerequisites of importance for conducting collaborative research. Compared to larger-scale fisheries, most exploited fish populations are data-limited, with only scattered and less available fisheries-dependent and fisheries-independent data (Dugan et al., 2010). Collaboration with fishers can be of larger relative importance to small-scale fisheries as a cost-efficient way to improve fisheries assessments of the status and vulnerability of important stocks (Reis-Filho et al., 2023). Fishing areas are often limited in small-scale fisheries, so fishers often have deep knowledge of their fishing grounds.

Long-term success of participatory research depends on the incentives of stakeholders to participate (Feekings et al., 2019; Lundholm & Stöhr, 2014). In our case study, fishers likely had numerous incentives to collaborate. One factor that motivated fishers to participate was that the research topic came from fishers themselves and therefore aimed to solve their own important problems. Another factor was that the project enabled fishers to target fishing areas with gears that previously were not allowed. Fishers were also, hopefully, motivated to collaborate and learn.

Another crucial element determining the success of fisher–scientist collaborations is how fishers are approached and how the collaboration is designed (Kraan et al., 2013). In our study, an important issue was the balance between giving participating fishers freedom to plan and design their own activities and contributions and the optimal design from a statistical analysis perspective. On the one hand, giving fishers the freedom to adapt certain ideas to specific conditions in their fishing areas was a positive incentive for fishers to engage in the project. Fishers were accustomed to working in a flexible manner, by adapting to rapid changes in weather and the behavior of their target fishes. On the other hand, without a common sampling strategy, the data collected were more difficult to analyze and could be useless for statistical testing of hypotheses. This challenge can be partly solved by using advanced and flexible modeling techniques that are now available for data analyses.

On the basis of our experience from this project, we recommend that fishers be involved in collecting data, in addition to collecting statistics on landing weights and effort that they are now required to provide (in our case on a monthly basis). However, fishers should also be involved in setting objectives and designing studies, so they can fully understand how results will be used in management. Fishers should also receive fair compensation for extra work of being involved in scientific studies that takes time away from their other work and thereby negatively affects their businesses. In the future, reporting of data from fishers can be simplified through the use of digital real-time observation reporting tools (van Helmond et al., 2019).

4.4 | Conclusions

Results of our case study encompass several years of intense collaborative research. Our results showed that urgent management problems of relevance to stakeholders can be solved by fisher and scientist collaboration. Our results showed that similar fisheries can reach selectivity and viability targets if fishing efforts can be allocated to specific areas and seasons. We recommend that pontoon traps be further investigated as fishing gear for shallow, near-shore areas in lakes to allow fishing where gillnetting leads to unacceptable bycatch and where bycatch of crayfish is high. We also recommend that the net height and mesh size of gillnets in lake fisheries should be selected carefully to account for the selectivity of target and non-target species.

Collaborating in research with stakeholders is time-consuming and requires much effort in planning and disseminating results, but the benefits outweigh such costs. Data collection is enabled on larger spatial and temporal scales than traditional scientific surveys and leads to better integration of fisher knowledge and expertise with scientific knowledge. Such co-constructed knowledge for the the management of small-scale fisheries may contribute to achieving more responsible, sustainable, and productive fisheries.

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CONFLICT OF INTEREST STATEMENT

None.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study will be made publically available online via the Swedish university of agricultural sciences. However, anything that relates to private fishermen and their businesses will be anonymized.

ETHICS STATEMENT

Our study was conducted under the ethic approval of SJR Dnr 6229-2020.

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REFERENCES

Bell, J.D. & Lyle, J.M. (2016) Post-capture survival and implications for by-catch in a multi-species coastal gillnet fishery. *PLoS One*, 11(11), e0166632. Available from: https://doi.org/10.1371/journal.pone.0166632

Berkes, F., Mahon, R., McConney, P., Pollnac, R. & Pomeroy, R. (2001) *Managing small-scale fisheries. Alternative directions and methods*. Ottawa, Canada: International Development Research Centre.

Bernatchez, L., Chouinard, A. & Guoqing, A.L. (2008) Integrating molecular genetics and ecology in studies of adaptive radiation: whitefish, Coregonus sp., as a case study. *Biological Journal of the Linnean Society*, 68, 173–194. Available from: https://doi.org/10.1111/j.1095-8312.1999.tb01165.x

Blomquist, G.E. & Swahnberg, H. (2020) Ekonomisk och strukturell data rörande svenskt insjöfiske. *Jordbruksverket Rapport*, 19, 52.

Bryhn, A.C., Grände, A., Setzer, M., Johansson, K.-M. & Bergström, L. (2021) Ecosystem-based fisheries management is attainable, affordable, and should be viewed as a long-term commitment: experiences from Lake Vättern, Sweden. *Journal of Great Lakes Research*, 47(5), 1437–1445. Available from: https://doi.org/10.1016/j.jglr.2021.08.012

Buchanan, S., Farrell, A.P., Fraser, J., Gallaugher, P., Joy, R. & Routledge, R. (2002) Reducing gill-net mortality of incidentally caught coho Salmon. *North American Journal of Fisheries Management*, 22, 1270–1275. Available from: https://doi.org/10.1577/1548-8675(2002)022<1270:RGNMOI>2.0.CO;2

Clay, T.A., Small, C., Tuck, G.N., Pardo, D., Carneiro, A.P.B., Wood, A.G. et al. (2019) A comprehensive large-scale assessment of fisheries bycatch risk to threatened seabird populations. *Journal of Applied Ecology*, 56, 1882–1893. Available from: https://doi.org/10.1111/1365-2664.13407

deWeber, J.T., Rösch, R., Baer, J. & Brinker, A. (2021) Long-term changes in body condition and gillnet selectivity in Lake Constance pelagic spawning whitefish (Coregonus wartmanni). *Canadian Journal of Fisheries and Aquatic Sciences*, 78, 841–855. Available from: https://doi.org/10.1139/cjfas-2020-0231

dos Santos, M.N., Gaspar, M., Monteiro, C.C. & Erzini, K. (2003) Gill net selectivity for European hake Merluccius merluccius from southern Portugal: implications for fishery management. *Fisheries Science*, 69, 873–882.

Dugan, P., Delaporte, A., Andrew, N., O'Keefe, M. & Welcomme, R. (2010) *Blue harvest: inland fisheries as an ecosystem service*. The WorldFish Center Working Papers.

FAO. (2003) *The ecosystem approach to fisheries*. FAO technical guidelines for responsible fisheries. (Suppl. 2), Vol. 4. Rome: FAO, p. 112.

Feekings, J., O'Neill, F., Krag, L., Ulrich, K. & Malta, T.V. (2019) An evaluation of European initiatives established to encourage industry-lead development of fishing gears. *Fisheries Management and Ecology*, 26, 650–660. Available from: https://doi.org/10.1111/fme.12379

Fischer, J., Jorgensen, J., Josupeit, H., Kalikoski, D. & Lucas, C.M. (2015) *Fishers' knowledge and the ecosystem approach to fisheries: applications, experiences and lessons in Latin America*. FAO Fisheries and Aquaculture Technical Paper No. 591. FAO: Rome, p. 278.

Frid, C. (2005) The role of marine science in participatory fisheries governance. In: Gray, T.S. (Ed.) *Particpation in fisheries governance*. Dordrecht, the Netherlands: Springer AA, pp. 231–247.

Gerdeaux, D., Anneville, O. & Hefti, D. (2006) Fishery changes during re-oligotrophication in 11 peri-alpine Swiss and French lakes over the past 30 years. *Acta Oecologica*, 30(2), 161–167.

Gilman, E., Hall, M., Booth, H., Gupta, T., Chaloupka, M., Fennell, H. et al. (2022) A decision support tool for integrated fisheries bycatch management. *Reviews in Fish Biology and Fisheries*, 32, 441–472. Available from: https://doi.org/10.1007/s11160-021-09693-5

Håkanson, L. (2010) Great Lakes – form and function, as exemplified using data from Lake Vänern, the fourth largest Lake in Europe. In: Donovan, J.S. (Ed.) *Great Lakes: ecology, management and conservation*. New York, USA: Nova Science Publishers, Inc.

Hall, M.A. (1996) On bycatches. *Reviews in Fish Biology and Fisheries*, 6, 319–352. Available from: https://doi.org/10.1007/BF00122585

Hall, S.J. & Mainprize, B.M. (2005) Managing by-catch and discards: how much progress are we making and how can we do better? *Fish and Fisheries*, 6(2), 134–155. Available from: https://doi.org/10.1111/j.1467-2979.2005.00183.x

Hansen, M.J., Madenijan, C.P., Selgeby, J.H. & Helser, T.E. (1997) Gillnet selectivity for lake trout (*Salvelinus namaycush*) in Lake Superior. *Canadian Journal of Fisheries and Aquatic Sciences*, 54, 2483–2490.

Harrod, C., Mallela, J. & Kahilainen, K. (2010) Phenotype-environment correlations in a putative whitefish adaptive radiation. *Journal of Animal Ecology*, 79(5), 1057–1068 Available from: http://www.jstor.org/stable/40835568

HaV & SCB. (2023) Recreational fishing in 2022. Jo 57 SM 2301, 24 pp. ISSN: 1654-417X (Online) URN:NBN:SE:SCB-2023-JO57SM2301_pdf.

Hemmingsson, M., Fjälling, A. & Lunneryd, S.-G. (2008) The pontoon trap: description and function of a seal-safe trap-net. *Fisheries Research*, 93, 357–359. Available from: https://doi.org/10.1016/j.fishres.2008.06.013

Hilborn, R. (2007) Moving to sustainability by learning from successful fisheries. *Ambio*, 36(4), 296–303. Available from: https://doi.org/10.1579/0044-7447(2007)36

Hovgård, H. & Lassen, H. (2000) *Manual on estimation of selectivity for gill-net and longline gears in abundance surveys*. FAO fisheries technical paper. No. 397. Rome, FAO. 2000. 84p.

Huntington, H.P. (2000) Using traditional ecological knowledge in science: methods and applications. *Ecological Applications*, 10, 1270–1274. Available from: https://doi.org/10.2307/2641282

Johnson, J.E., Jonas, J.L. & Peck, J.W. (2004) *Management of Commercial Fisheries Bycatch,with Emphasis on Lake Trout Fisheries of the Upper Great Lakes*. Michigan Department of Natural Resources Fisheries Division, Fisheries Research Report, 2070, 1–17.

Jonsson, T., Setzer, M., Pope, J.G. & Sandström, A. (2013) Addressing catch mechanisms in gillnets improves modelling of selectivity and estimates of mortality rates: a case study using survey data on an endangered stock of Arctic char. *Canadian Journal of Fisheries and Aquatic Sciences*, 70(10), 1477–1487. Available from: https://doi.org/10.1139/cjfas-2012-0472

Kallio-Nyberg, I., Veneranta, L., Saloniemi, I. & Salminen, M. (2018) Anadromous trout threatened by whitefish gill-net fisheries in the northern Baltic Sea. *Journal of Applied Ichthyology*, 34, 1145–1152. Available from: https://doi.org/10.1111/jai.13771

Kao, Y.-C., Rogers, M.W., Bunnell, D.B., Cowx, I., Qian, S.S., Anneville, O. et al. (2020) Effects of climate and land-use changes on fish catches across lakes at a global scale. *Nature Communications*, 11(1), 2526. Available from: https://doi.org/10.1038/s41467-020-14624-2

Kennelly, S.J. & Broadhurst, M.K. (2002) By-catch begone: changes in the philosophy of fishing technology. *Fish and Fisheries*, 3(4), 340–355. Available from: https://doi.org/10.1046/j.1467-2979.2002.00090.x

Kraan, M., Uhlmann, S., Steenbergen, J., Van Helmond, A.T.M. & Van Hoof, L. (2013) The optimal process of self-sampling in fisheries: lessons learned in The Netherlands. *Journal of Fish Biology*, 83(4), 963–973. Available from: https://doi.org/10.1111/jfb.12192

Langseth, B.J. & Cottrill, A. (2015) Influence of fishing practices on lake trout bycatch in the Canadian lake-whitefish commercial fishery in Lake Huron. *Journal of Great Lakes Research*, 41, 280–291. Available from: https://doi.org/10.1016/j.jglr.2014.12.014

Liljestrand, E.M., Bence, J.R. & Deroba, J.J. (2023) Applying a novel state-space stock assessment framework using a fisheries-dependent index of fishing mortality. *Fisheries Research*, 264, 106707. Available from: https://doi.org/10.1016/j.fishres.2023.106707

Lumb, C.E., Johnson, T.B., Cook, H.A. & Hoyle, J.A. (2009) Comparison of Lake whitefish (*Coregonus clupeaformis*) growth, condition, and energy density between lakes Erie and Ontario. *Journal of Great Lakes Reserarch*, 33, 314–325. Available from: https://doi.org/10.3394/0380-1330(2007)33[314:COLWCC]2.0.CO;2

Lundholm, C. & Stöhr, C. (2014) Stakeholder dialogues and shared understanding: the case of co-managing fisheries in Sweden. *Sustainability*, 6(7), 4525–4536. Available from: https://doi.org/10.3390/su6074525

Lundin, M. (2014) *Size selection of fish in the trap fisheries of the Baltic and Bothnian seas*. PhD-thesis, Umeå, Sweden, SLU.

Lunneryd, S.-G., Fjälling, A. & Westerberg, H. (2003) A large-mesh salmon trap: a way of mitigating seal impact on a coastal fishery. *ICES Journal of Marine Science*, 60(6), 1194–1199. Available from: https://doi.org/10.1016/S1054-3139(03)00145-0

Mackinson, S., Raicevich, S., Kraan, M., Magudia, R. & Borrow, K. (2015) *Good Practice Guide: Participatory Research in Fisheries Science*. Available from: http://gap2.eu/outputs/pr-handbook/

Mackinson, S., Wilson, D.C., Galiay, P. & Deas, B. (2011) Engaging stakeholders in fisheries and marine research. *Marine Policy*, 35(1), 18–24. Available from: https://doi.org/10.1016/j.marpol.2010.07.003

Marjomäki, T.J., Paloniemi, M., Keskinen, T., Kuha, J. & Karjalainen, J. (2015) Empirical estimation of accumulation-induced change in gill net catchability: mind the observation errors. *The Open Fish Science Journal*, 8(1), 13–22. Available from: https://doi.org/10.2174/1874401X01508010013

Millar, R.B. & Fryer, R.J. (1999) Estimating the size-selection curves of towed gears, trap, nets and hooks. *Reviews in Fish Biology and Fisheries*, 9, 89–116. Available from: https://doi.org/10.1023/A:1008838220001

Müller, R., Breitenstein, M., Bia, M.M., Rellstab, C. & Kirchhofer, A. (2007) Bottom-up control of whitefish populations in ultra-oligotrophic Lake Brienz. *Aquatic Sciences*, 69(2), 271–288. Available from: https://doi.org/10.1007/s00027-007-0874-5

Museth, J., Sandlund, O.T. & Borgstrøm, R. (2007) Coexistence between introduced whitefish (Coregonus lavaretus) and native Arctic char (Salvelinus alpinus) depends on heavy whitefish exploitation. In: Jankun, M., Brzuzan, P., Hliwa, P. & Luczynski, M. (Eds.) *Biology and Management of Coregonid Fishes*. Stuttgart: Schweizerbart Science Publishers, pp. 343–350.

Northridge, S., Kingston, A., Mackay, A. & Lonergan, M. (2011) *Bycatch of vulnerable species: understanding the process and mitigating the impacts*. Final report to Defra marine and fisheries science unit, project no MF1003. University of St Andrews. Defra, London, 99pp.

Nusslé, S., Bornand, C.N. & Wedekind, C. (2009) Fishery-induced selection on an alpine whitefish: quantifying genetic and environmental effects on individual growth rate. *Evolutionary Applications*, 2(2), 200–208.

Prchalová, M., Mrkvička, T., Peterka, J., Čech, M., Berec, L. & Kubečka, J. (2011) A model of gillnet catch in relation to the catchable biomass, saturation, soak time and sampling period. *Fisheries Research*, 107(1–3), 201–209. Available from: https://doi.org/10.1016/j.fishres.2010.10.021

Radomski, P., Anderson, C.S., Bruesewitz, R.E., Carlson, A.J. & Borkholder, B.D. (2020) An assessment model for a standard gill net incorporating direct and indirect selectivity applied to walleye. *North American Journal of Fisheries Management*, 40, 105–124. Available from: https://doi.org/10.1002/nafm.10384

Reis, E.G. & Pawson, M.G. (1999) Fish morphology and selectivity by gillnets. *Fisheries Research*, 39, 263–273.

Reis-Filho, J.A., Ramos-Filho, F., Castello, L. & Giarrizzo, T. (2023) I fish, therefore I monitor: participatory monitoring to assess inland small-scale fisheries. *Environmental Management*, 72, 540–557. Available from: https://doi.org/10.1007/s00267-023-01819-8

Roe, J.H., Morreale, S.J., Paladino, F.V., Shillinger, G.L., Benson, S.R., Eckert, S.A. et al. (2014) Predicting bycatch hotspots for endangered leatherback turtles on longlines in the Pacific Ocean. *Proceedings of the Royal Society B*, 281, 20132559. Available from: https://doi.org/10.1098/rspb.2013.2559

Rösch, R., Baer, J. & Brinker, A. (2018) Impact of the invasive three-spined stickleback (Gasterosteus aculeatus) on relative abundance and growth of native pelagic whitefish (Coregonus wartmanni) in upper Lake Constance. *Hydrobiologia*, 824, 243–254. Available from: https://doi.org/10.1007/s10750-017-3479-6

Samaranyaka, A., Engås, A. & Jørgensen, T. (1997) Effects of hanging ratio and fishing depth on the catch rates of tuna gillnets in Sri Lankan waters. *Fisheries Research*, 29, 1–12.

Sandström, A., Andersson, M., Asp, A., Bohman, P., Edsman, L., Engdahl, F. et al. (2014) Population collapses in introduced non-indigenous crayfish. *Biological Invasions*, 16, 1961–1977. Available from: https://doi.org/10.1007/s10530-014-0641-1

Sandström, A., Axenrot, T., Asp, A. & Ståhl, J. (2016) Hydroakustisk undersökning vintertid av djuplekande sik i Vättern. Using mobile hydro-acoustics to monitor deep-spawning aggregations of whitefish in Lake Vättern. *Vättern Fakta*, 2, 14 pp. Available from: https://vattern.org/fakta-2-hydroakustisk-undersokning-vintertid-av-djuplekande-sik-i-vattern/

Sandström, A., Engdahl, F. & Edsman, L. (2017) Fiskets fångster och trender för Vätterns kommersiella fisk- och kräftarter. *Vätternvårdsförbundet Rapport*, 126, 105–122 Available from: http://www.vattern.org/wp-content/uploads/2018/05/Årsskrift-2017-pussel-fin.pdf

SLU Fiskbarometern. (2023) SLU Fiskbarometern (2024). Resursöversikt 2023. Available from: https://fiskbarometern.se [Accessed 13 March 2024]

Svärdson, G. (1979) Speciation of Scandinavian Coregonus. *Report of the Institute of Freshwater Research Drottningholm*, 57, 1–95.

van Helmond, A.T.M., Mortensen, L.O., Plet-Hansen, K.S., Ulrich, C., Needle, C.L., Oesterwind, D. et al. (2019) Electronic monitoring in fisheries: lessons from global experiences and future opportunities. *Fish and Fisheries*, 21, 162–189. Available from: https://doi.org/10.1111/faf.12425

Veneranta, L., Pakarinen, T., Jokikokko, E., Kallio-Nyberg, I. & Harjunpää, H. (2017) Mortality of Baltic sea trout (Salmo trutta) after release from gillnets. *Journal of Applied Ichtyology*, 34, 49–57. Available from: https://doi.org/10.1111/jai.13517

Wilson, D.C., Nielsen, J.R. & Degnbol, P. (2003) *The fisheries co-management experience: accomplishments, challenges and prospects*. Netherlands: Springer Science & Business Media.

Wood, S.N. (2006) *Generalized additive models. An introduction with R*. Boca Raton FL: Chapman and Hall/CRC.

Zuur, A.F., Ieno, E.N. & Smith, G.M. (2007) *Analysing ecological data*. New York: Springer Science.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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