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Preface to the Special Issue “Ecologically sustainable fishing”: Project KESKALA background, objectives and conclusions

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‘Ecosystem-based fisheries management — criteria for the sustainable fishing’ project was started in 2005. The general aims were to define the main factors that affect the state and demography of fish populations, and to develop a strategy for fishing and fish stock management abiding by the principles of sustainable use. The key objectives were to investigate (1) the effects of fishing on abundance, structure, production and genetic characteristics of fish populations, (2) the effects of maternal traits on the amount and quality of offspring, (3) the effects of piscivore fishing on the ecosystem, (4) the factors affecting the interactions between fishes, and (5) the reliability of different methods in estimating fish population abundance and structure.

The perch (*Perca fluviatilis*), pike (*Esox lucius*) and pikeperch (*Sander lucioperca*) were chosen as the main target species because they are the most abundant species in the recreational catches in Finland (Natural Resources Institute Finland 2015), but little studied from the above-mentioned points of view. The maternal effects (i.e., the effects of female traits on the offspring characteristics) were studied in all three species. Special attention was paid to the role of large individuals in maintaining population renewability and to the effects of different fishing strategies on the food web structure and biological interactions. The experimental study lakes were located in the Evo forest area in southern Finland (61°13´N, 25°12´E). In addition, studies were carried out in some larger lakes in southern and central Finland (Roikonen 2014, Vainikka *et al.* 2017). The project was conducted in co-operation by the University of Helsinki and the Finnish Game and Fisheries Research Institute (as of 1 Jan. 2015 Natural Resources Institute Finland), and financially supported mainly by the Bergsrådet Bror Serlachius Foundation.

The project was divided into three periods:

1. 2005–2007: Investigation of the initial situation in the experimental lakes (n = 7, 2.1–13.8 ha, close to pristine). Studied parameters for pike, perch and roach (*Rutilus rutilus*) were species-specific density, age and size-structure, production and food consumption. Additionally, the density and composition of zoobenthos, chaoborids and zooplankton as well as primary production, trophic status and physico-chemical parameters were investigated in the studied lakes.

2. 2008–2012: Regulation of the pike and perch populations in the experimental lakes. The effects of minimum length limit of 40 cm and harvestable slot length limit of 40-64.9 cm on pike population density, biomass and size-structure were studied. Perch populations were regulated by intensive fishing in an artificially divided lake: one population was exposed to negatively size-selective fishing (large individuals released) and the other to non-selective fishing (all length classes targeted). The factors affecting the interactions between pike, perch and roach (including water colour, temperature, predation risk and gender) were explored in field and laboratory experiments. The effects of pikeperch fisheries regulation were monitored in the larger lakes.
3. 2013–2017: Continued monitoring and modelling whose main purpose was to study, how the fish, zoobenthos and zooplankton communities recovered from heavy fishing pressure. During this period also the collected data were analysed, modelled (pikeperch) and published.

Altogether, the project yielded over 20 scientific papers published in international journals and academic theses (for the list *see* http://www.helsinki.fi/keskala/julkaisut/artikkelit.htm). The research highlighted that large-sized fish individuals are important for successful reproduction as a positive maternal effect was observed in all of the target species (Olin *et al*. 2012, Kotakorpi *et al*. 2013, Roikonen 2014). These large individuals are also most vulnerable to fishing. Intensive fishing decreased particularly the number of valuable large-sized and old fish (Tiainen *et al*. 2017). Experimental studies simulating global climate change revealed that decreasing water transparency and increasing temperature hindered feeding of visually hunting predatory fishes (Estlander and Nurminen 2014, Estlander *et al*. 2015). This is emphasized in particular among females, the growth rate of which decreased more than that of males (Horppila *et al*. 2011, Estlander *et al*. 2012, 2017c). Environmental changes also affect intra- and interspecific competition of predatory fishes resulting in decreased growth (Estlander *et al*. 2010, Horppila *et al*. 2010, Olin *et al*. 2010, Nurminen *et al*. 2014). As a consequence, there was a smaller number of large individuals to be caught.

One of the most important outcomes of the project from the point of view of sustainable fishing was that the existence of large fish individuals is of crucial importance for recruitment success of the population. The number and quality of offspring (larger size, higher starvation resistance) of large female spawners are much better than those of small ones (Olin *et al*. 2012, Kotakorpi *et al*. 2013, Roikonen 2014). Without a maximum length limit, intensive fishing of pike or perch with annual target catch of 50% of biomass in targeted length-range resulted in a disappearance of large individuals from the population in four years (Tiainen *et al*. 2017, Olin *et al*. 2017a). When harvestable slot length limit (pike) or maximum length limit (perch) were used, also large and old individuals were retained in the population though their number gradually decreased when fishing pressure was high (Tiainen *et al*. 2017, Olin *et al*. 2017a). The result underlines the potential use of slot limit or maximum length limit to manage fisheries sustainably.

We observed several fishing-induced compensatory and depensatory mechanisms in the pike and perch populations. In pike, compensative change in the maternal effect occurred, and females produced heavier eggs after the intensive fishing (Kotakorpi *et al*. 2013). As a negative effect, the size-structure of the spawning stock truncated (Tiainen *et al*. 2017). In perch, fry production was greatly increased due to reduced cannibalism and decreased age and size at maturity and higher fecundity (Olin *et al*. 2017a). An important depensatory mechanism was the decrease of the size of offspring both at the population (decreased average size of spawners) and the individual levels (decreased egg mass in relation to female size) (Olin *et al*. 2017a). According to the model-based evaluation of pikeperch stock management, the minimum length limit should be higher for fast-growing stocks and lower for strongly food-limited stocks to ensure the highest yields (Vainikka *et al*. 2017). Harvestable slot length limit allows the higher rate of fishing mortality but to ensure the maximal stability of yield and minimal evolutionary effect, fishing mortality rates should be relatively low.

In the experimental studies, we observed that the fishing had a cascading effect on the ecosystem, depending on the regulation of fishing (size limits). The intensive perch removal in the divided lake clearly affected the composition of the benthic community (Grönroos 2009). The total density quadrupled from 2007 to 2009 when annual perch removal was 16%–43% of the biomass. Strongest increase was observed in chironomids, but also the density of caddisflies and mayflies increased. The total macroinvertebrate biomass increased during the study period in the lake side where all size classes of perch were targeted and remained at the same level or fluctuated in the lake side where individuals ≥ 16 cm were released. The benthic community size-structure followed the biomass pattern. In contrast to total biomass, no clear response in total macroinvertebrate density to size-selective fishing was found but rather the macroinvertebrate density correlated with the total perch density (L. Nurminen unpubl. data). We also found that the ecosystem effects of fishing can be highly unpredictable and dependent on e.g. the behavioural change of the targeted fish species or the compensatory dynamics in prey community. Unexpectedly, increased perch density as a response to intensive fishing resulted in an increase in the biomass of large-sized but a decrease in the biomass of smaller and dominant cladoceran species (Estlander *et al*. 2017b). This was explained by changed habitat preference and ontogenetic shift of perch and competitive interactions among zooplankton species. As a conclusion, the ecosystem-based management approach and also the precautionary principle should be acknowledged in fisheries management.

In addition to fish predation pressure, our results suggest that water transparency affects zooplankton dynamics. For example, our results showed that the increasing concentrations of humic substances that modify the light environment underwater may alter the diurnal behaviour and habitat use of plant-attached zooplankton in lakes with relatively high predation pressure (Estlander *et al*. 2017a). In addition, Estlander *et al*. (2009, 2010) showed that the importance of the littoral zone as a refuge for zooplankton decreases with decreasing transparency. The darker the water colour the less fish tend to feed on littoral zooplankton species or macrophyte associated benthic macroinvertebrates.

Global warming is predicted to raise lake water temperatures and decrease water transparency. This can change roach population structure and production and therefore modify the interactions between roach and other fishes e.g. perch and pike (Olin *et al*. 2017b). Changes in water quality (e.g. water colour, temperature and oxygen concentration can also affect the reliability of fish community estimates (Olin *et al*. 2016). In general, large fish are considered more sensitive to environmental variation due to higher energy demand than smaller individuals. Similarly, large individuals require more food to maintain body functions and are thus more sensitive to resource and food scarcity. These size-specific responses to environmental gradients are also sex-dependent in species that exhibit sexual size dimorphism. The results of Estlander *et al*. (2015) revealed that the combined effect of water transparency and temperature on the feeding rate of fish is gender-dependent: the feeding rate of females decreased more than that of males. The experimental results were also supported by field data that revealed a negative relation between water transparency and the magnitude of sexual size dimorphism in perch. Rising temperatures and decreasing water transparency may potentially decrease fish size in a sex-dependent manner (Estlander *et al*. 2017c). As female size is one of the main demographic traits determining the reproductive success of a fish population, changing environments may have unexpected and far-reaching consequences for fish population dynamics (Estlander *et al*. 2015).

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