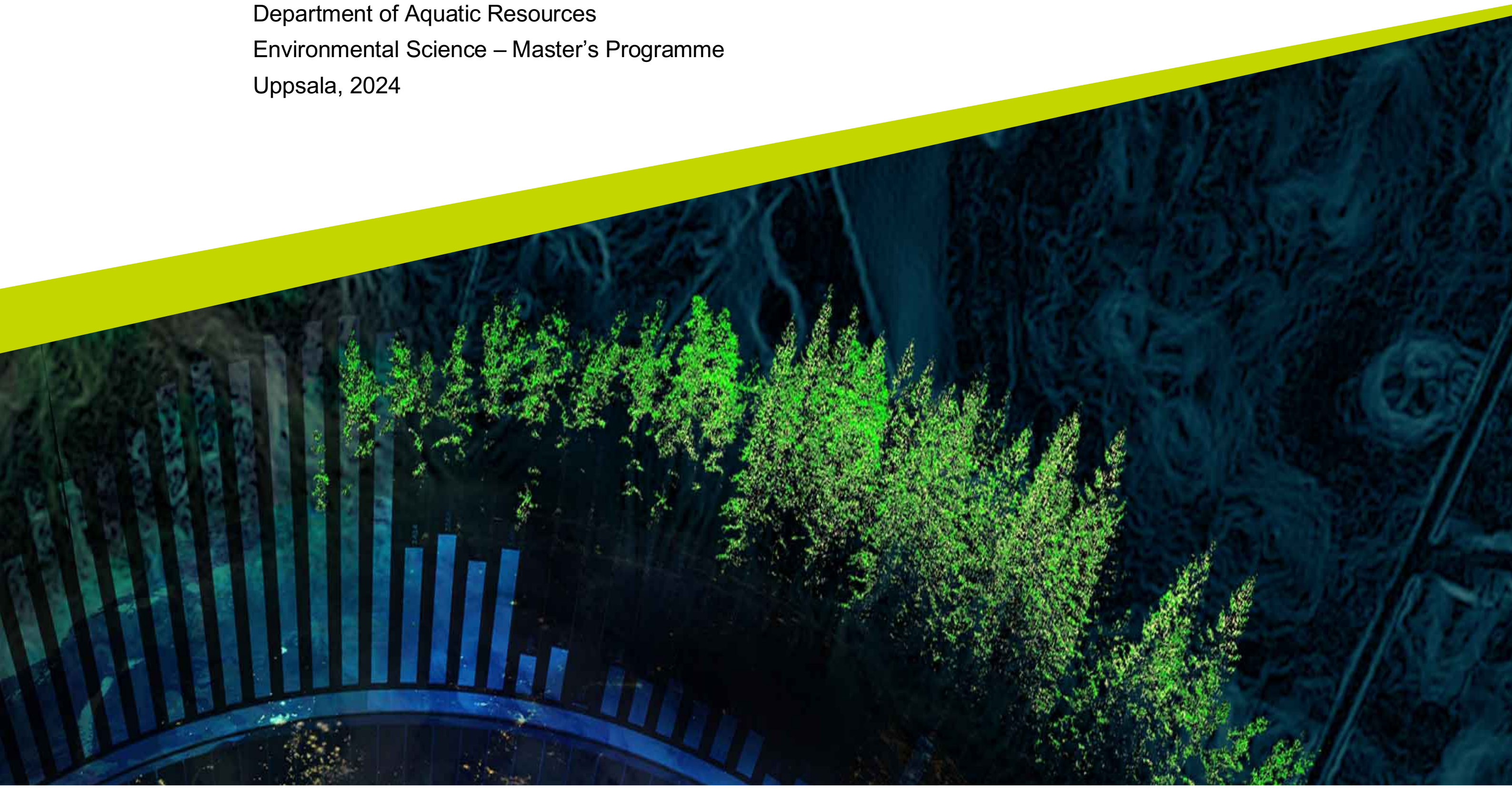
How big is a perch in Sweden?

A study of L90 size in *Perca fluviatilis*

Cameron Camillo

Master thesis in Environmental Science, A2E • 30 credits
Swedish University of Agricultural Sciences, SLU
Department of Aquatic Resources
Environmental Science – Master's Programme
Uppsala, 2024



How big is a perch in Sweden. A study of L90 size in *Perca fluviatilis*

Cameron Camillo

Supervisor:	**Jens Olsson, SLU, Department of Aquatic Resources**
Co-supervisor:	Kerstin Holmgren, SLU, Department of Aquatic Resources
Examiner:	Magnus Huss, SLU, Department of Aquatic Resources

Credits:	30 credits
Level:	Second cycle, A2E
Course title:	Master thesis in Environmental Science, A2E
Course code:	EX0901
Programme/education:	Environmental Science – Master's Programme
Course coordinating dept:	Department of Aquatic Resources
Place of publication:	Uppsala
Year of publication:	2024
Copyright:	All featured images are used with permission from the copyright owner.

Keywords: Perca fluviatilis, Perch, L90, Aquatic System, Sweden

Swedish University of Agricultural Sciences
Faculty of Natural Resources and Agricultural Sciences
Department of Aquatic Resources

Abstract

Due to its wide distribution and predatory role, *Perca fluviatilis* is a key component of the Swedish fish fauna, contributing to the food web and ecosystem functionality. Nevertheless, little is known about the factors that influence the size of large individuals within perch populations. Few studies have examined and compared spatial and temporal patterns of the size of large perch between different aquatic systems. The data used for this thesis are from SLU Aqua's NORS and KUL databases, covering three ecosystem types: coastal areas, large lakes, and small lakes. The main objective of the thesis was to determine the mean L90, a size indicator used for large perch, and to identify possible size-based spatial gradients in the study systems. Data were selected from gillnet surveys, with a minimum perch size selection of 15 cm. Results showed a slight increase in L90 over time and a difference across the systems. The 2016-2022 mean size of a large Swedish perch was 27.3 cm (respectively, coast: 26.1 cm, large lakes: 27.2 cm, and small lakes: 28.7 cm). A significant difference in the mean L90 between the small lake and coastal systems was detected during these six years. Also, the analysis of L90 averages revealed no significant spatial gradient within systems, although mean differences were observed in several geographically close monitoring areas. These variations suggest the existence of local growth patterns, unique habitat characteristics, environmental factors, differences in the level of human impact, and/or geographical isolation. Using the L90 indicator in the three systems studied raised some points. Although suitable for fish populations in coastal areas and applicable to large lakes, its practical use would require appropriate adjustments to the system. Indeed, further studies would be needed to determine whether the L90 threshold value in the other two systems should be identical to that in coastal areas. This study is the first L90 analysis in this system for small lakes since large fish are not involved in assessing the good status of this ecosystem. As the size and number of fish caught in many small lakes were below the data inclusion threshold, only a small subset of all lakes caught was included in the analysis. Of the 2,000 perch lakes sampled in the SLU database, only a maximum of 86 small lakes were included, representing less than 5% of the total number of lakes. To conclude, by conducting L90 comparisons between coastal, large, and small lake systems for the first time, the analysis revealed several interesting patterns with new and significant results. Furthermore, this thesis confirms the need for future research on large individuals to focus on specific sections that contain local populations with distinct mean L90 despite close geographical proximity to understand how environmental, genetic, and anthropogenic factors influence large perch size.

Keywords: Perca fluviatilis, Perch, L90, Aquatic System, Sweden

Table of contents

List of Tables

List of Figures

Abbreviations

ANOVA:	Analysis of variance
ANCOVA:	Analysis of covariance
BQE:	Biological Quality Element
BSAG:	Baltic Sea Action Group
EC:	European Commission
EU:	European Union
GES:	Good Environmental Status (sensu MSFD)
HELCOM:	The Baltic Marine Environment Protection Commission
HaV:	Havs och Vattenmyndigheten
L90:	Length at 90th percentile
MSFD:	Marine Strategy Framework Directive
SEPA:	Swedish Environmental Protection Agency
WFD:	Water Framework Directive

1 Introduction

The importance of fish size in structuring aquatic ecosystems, specifically in the pelagic environment, was highlighted in the work of Sheldon et *al.* in the 1970s (Sheldon *et al.*, 1977). For living organisms, the diversity of body sizes is a fundamental trait (Cohen *et al.,* 1993). In the marine environment, the food web is large and complex. Most species are predators and can consume prey two to three orders smaller than their mass (Pope *et al.*, 1994). Therefore, fish significantly impact ecosystem dynamics as predators through trophic cascades (Pauly *et al.*, 1998). Studying the size of fish offers an essential understanding of how populations respond to various pressures since it is significantly influenced by many aspects of a species' physiology and ecological performance (Keppeler *et al.,* 2020). Indeed, the metabolism, mobility, territory, foraging, vulnerability to predators, reproduction, and longevity at different life stages are all affected by size (Keppeler *et al.*, 2020). Size has, hence, a decisive impact on the dynamics of populations, communities, and ecosystems (Keppeler *et al.*, 2020). Understanding the size structure of fish populations offers crucial insights into their reproductive capacity (Olin *et al.*, 2012), growth pattern, and overall stability (Hixon *et al.*, 2014; van Overzee and Rijnsdorp, 2015). The absence or scarcity of small-sized fish may suggest reproductive deficits, while the shortage of large-sized fish may indicate slow growth or elevated mortality of mature individuals (Neumann and Allen, 2007).

Different factors influence the size distribution of individual organisms within a population. It could be abiotic and biotic factors such as genetic variability, environmental characteristics, and individual competitive interactions (Shin *et al.*, 2005). In addition, environmental gradients, for example, light conditions (Radke and Gaupisch, 2005), temperature (Arranz *et al.*, 2016; van Dorst *et al.*, 2019; Lindmark *et al.*, 2023), pH (Holmgren *et al.*, 2016), and oxygen (Christensen, *et al.,* 2020), can further accentuate the size structure within fish populations (Holmgren and Petersson, 2023) in affecting their ecophysiology (Sheridan and Bickford, 2011; Cresswell *et al.*, 2019). Besides environmental gradients and variation and the inherited genetic characteristics, the most significant drivers for the size structure of fish populations are human activities such as fishing (Shin *et al.*, 2005; Barnett *et al.*, 2017) and climate change (Sheridan and Bickford, 2011; Queirós *et al.*, 2018). The interplay of these factors exerts selective pressure on diversity and size structure (Bianchi *et al.*, 2000), disrupting food webs and interactions, particularly predation and competitive dynamics (Jenkins *et al.*, 1999; Mitchell *et al.*, 2019).

In Sweden, the small and large lakes and the Baltic coastal ecosystems are managed separately, considering freshwater and marine environments. However, responsibility for fisheries management varies according to each system's ownership nature. Fishing in Swedish public waters, which include the sea and the five largest lakes (Vänern, Vättern, Mälaren, Hjälmaren, and Storsjön), is under the state agency responsibility of Havs och Vattenmyndigheten (HaV) (Länsstyrelsen Östergötland, 2023). It involves compliance with established regulations on fish size, fishing seasons, designated fishing areas, and authorized species, which apply equally to Swedish citizens and foreigners (Länsstyrelsen Östergötland, 2023). Nevertheless, state management of fishing activities does not extend to other freshwater systems, which are often privately owned (van den Heuvel *et al.*, 2020). In these waters, fishing management and monitoring vary from owner to owner, making it difficult to generalize a specific management status (Havsmiljoinstitutet, 2021). Indeed, owners are responsible for fishing rights and licenses, practices, and implementing fish conservation measures (van den Heuvel *et al.*, 2020).

Among the most popular fish caught in Sweden, both commercially and recreationally, is *Perca fluviatilis,* the European or Common Perch (Olsson *et al.,* 2015), hereafter referred to as perch (Fig.1).

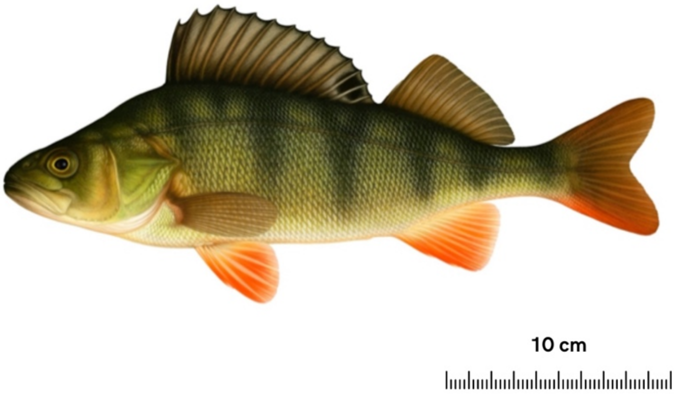


Figure 1. Illustration of Perca fluviatilis (adapted from Linda Nyman, SLU, 2023a)

Its scientific name, derived from Latin, refers to the river habitat (SLU, 2023a). The perch has two dorsal fins, with the first being spiny and the second softer (SLU, 2023a). It has dark vertical stripes along its flanks, a gray-green back, a shaded body, and a white belly (SLU, 2023a) with orange-red pelvic, caudal, and anal fins (Marine Finland, 2023).

The perch is a freshwater species living in lakes and sheltered, shallow marine areas (Snickars *et al.*, 2010). It has a wide distribution in Sweden, and it is one of the predominant species (Tammi *et al.*, 2003; SLU, 2023b) throughout the coastal areas of the Baltic Sea and the Gulf of Bothnia (HaV, 2020a) and in inland lakes (Appendix 1). As a top predator, the perch influences these system's structure and food web functioning (Persson *et al.*, 2003; Ljunggren *et al.*, 2010; Donadi *et al.*, 2017). According to the Swedish 2020 Red List (SLU Artdatabanken, 2020), the species' status is of minor concern since the 2000s (SLU, 2023a).

The perch is a species most commonly caught by small-scale coastal fishing in the Baltic Sea (HELCOM, 2023a), which is highly valued for commercial (Dieterich *et al*., 2004) and recreational fishermen (Vainikka *et al.,* 2012; Heermann *et al*., 2013). However, estimates of the extent of recreational fishery catches and their development in Sweden are subject to considerable uncertainty (Sundelöf *et al*., 2022). Indeed, Sweden has no legislation concerning reporting recreational perch fishing in private or public waters. The data on this recreational activity comes mainly from voluntary surveys collected by non-governmental bodies. Therefore, compiling data on this type of fishing could present challenges due to the complexity of collecting information, which can introduce errors or biases in statistical analyses.

Earlier research has focused on various aspects of perch ecology, including recruitment in coastal areas (Nilsson *et al*., 2004), fishing impact (Haakana and Huuskonen, 2008; Heermann *et al*., 2013; Hansson *et al*., 2022), feeding habits (Chrysafi *et al*., 2021), and growth responses to environmental factors (Huss *et al*., 2019; van Dorst *et al*., 2019, 2020). More recently, studies have investigated the development of population abundance in the Baltic Sea, underscoring the heterogeneous nature of perch populations along the coastal areas, revealing both stable and declining population trends (Olsson, 2019). Also, perch size metric indicators showed positive responses to reduced fishing pressure, particularly those focusing on the largest individuals within the population (e.g., L90 and Lmax) (Östman *et al*., 2023). Other studies have also investigated the size structure of perch and the prevalence of large perch in Swedish lakes (Holmgren and Petersson, 2023). Nevertheless, a notable gap exists in understanding the factors driving the size of the largest fish within and between perch populations. Limited studies have examined the perch size structure's spatial and temporal patterns and variation within and across habitats. Despite ongoing research, there is still a need to improve the understanding of how the perch size varies between distinct aquatic systems. Indeed, research has yet to accurately compare the size of inland systems, such as small and large lakes, and marine systems, such as the Baltic Sea coast. This study intends to address changes in large perch size across diverse Swedish aquatic systems and explore potential correlations between size and spatial gradients on a specific indicator of large perch, the length of the fish at the 90 percentile of the size distribution in the population (L90). By gathering data from three distinct ecosystem types (coast, large lakes, and small lakes), this study aims to provide a holistic perspective on the size of a large perch in Sweden.

As a member of the European Union (EU), Sweden is committed complying with the Water Framework Directive (WFD) (2000/60/EC), adopted in 2000 (Eur-Lex., 2014), and the Marine Strategy Framework Directive (MSFD) (2008/56/EC) adopted in 2008 (Eur-Lex., 2017). These directives form the cornerstone of the regulatory framework for management to protect the quality and integrity of Sweden's aquatic environments and water systems (Adolfsson, 2010; Pihlajamäki *et al*., 2013; WISE, 2018; Puharinen, 2023). Both directives adhere to six-year monitoring cycles. The third WFD cycle started in 2022, while the third MSFD cycle will be initiated in 2024. Despite the divergence in cycle years, the shared aim of attaining good ecological status for aquatic environments facilitates continuous and complementary management of freshwater and marine resources. They ensure a unified approach to conserving aquatic ecosystems throughout the country and the EU.

In the Baltic Sea, the intergovernmental organization HELCOM assesses the environmental status of biodiversity using several core indicators, including the "size structure of coastal fish" (HELCOM, 2023a). This metric examines the size distribution of key fish species, such as perch in the Baltic Sea (HELCOM, 2023a), providing insight into Swedish coastal regions' environmental and ecological conditions. Nevertheless, perch and other fish species in Swedish freshwater bodies are not specifically monitored under the WFD. However, due to its distribution, predatory role, and high ecological and socio-economic importance, the perch represents a crucial component of the Swedish fish fauna. Consequently, the perch is an exemplary model for studying fish population dynamics and the temporal trends in size metrics.

This study examined the perch L90 in three distinct Swedish ecosystems (coastal areas, large lakes, and small lakes), focusing on the period 2016-2022. Each ecosystem comprises numerous sampled stations, with varying years of data collection per station. Each of these groups can be referred to as a system.

The objectives of this study were to answer the following questions:

1. What is the average L90 of perch within systems?
2. Does the L90 differ significantly between the systems?
3. Are there spatial gradients of the L90 within systems?
4. What abiotic or biotic factors could potentially influence the size of a large perch?

Data from Swedish fish monitoring programs were analysed to answer questions 1-3. Question 4 was approached in a more conceptual way, by a discussion about published knowledge on factors affecting the perch size, growth and L90.

2 Biology of perch and EU directives in aquatic systems

Perch populations are mainly sedentary, generally maintaining the same territory throughout their growth or within a distance of 10 to 15 kilometers (Sundelöf *et al.*, 2022). In the Baltic Sea, the perch can move between different coastal areas, especially during the breeding season, when it migrates to freshwater habitats to spawn (Sundelöf *et al.*, 2022). Perch is eurythermal and tolerates temperatures from 3 °C to 33.5 °C (Craig, 2000), as it tolerates a wide range of salinities.

2.1 Habitat preferences and spawning

Perch prefers shallow coastal areas with aquatic vegetation or other three-dimensional structures such as tree roots, rocks, submerged vegetation, and artificial structures such as jetties (SLU, 2023a). In winter, the perch inhabits deeper waters, generally close to the benthic region, at depths of up to 60 meters (SLU, 2023a). Despite their preference for warmer conditions, perch are active feeders even during the coldest winter months (SLU, 2023a). Seasonal migrations between near-coastal freshwater and brackish water areas are known for perch. Indeed, some populations migrate from brackish to freshwater habitats for spawning for a lower salinity (Lozys, 2004; Tibblin *et al.*, 2011). Nevertheless, some populations prefer to spawn in the coastal areas (Tibblin *et al.*, 2011). Spawning occurs between April and June (Sundelöf *et al.*, 2022). Shallow lakes are essential breeding grounds due to their relatively higher water temperature (Marine Finland, 2023). The eggs are attached to vegetation or other complex three-dimensional structures during this phase (SLU, 2023a).

2.2 Diet

Perch adopts different feeding and territorial behaviors depending on life stage and environmental conditions. When young, they are schooling, and as they grow, they become more solitary and territorial (Marine Finland, 2023). Young perch begin feeding on zooplankton, progressing to crustaceans and insect larvae, and by the age of one or two, they incorporate fish into their diet (Estlander *et al.*, 2012). As perch grow, the ratio of fish in their diet increases. Opting for a piscivorous diet correlates with accelerated growth (Marine Finland, 2023). Nevertheless, dietary preferences vary considerably among individuals. Some embrace a piscivorous diet, while others maintain a diet primarily focused on crustaceans and insect larvae (Marine Finland, 2023). This dietary choice encompasses consuming various fish species, including conspecifics (Persson *et al.*, 2003). Environmental factors such as water transparency or prey density (other species) influence these behaviors (Jacobsen *et al.*, 2015).

2.3 Maturity and growth

Depending on where it lives and the conditions, perch is often between 10 and 50 cm, generally weighing a maximum of 500g for the male and several kilos for the female (Sundelöf *et al.*, 2022). If conditions are conducive to good development, female perch can reach a maximum weight of around 3kg and a total length of about 60cm (Sundelöf *et al.*, 2022; SLU, 2023a). Females are generally larger than males. In coastal areas, individuals live from 10 to 15 years, and in freshwater, they can live up to 20 years (Sundelöf *et al.*, 2022).

Growth and age at sexual maturity depend on the environmental conditions, although growth in this species is progressive. Males reach sexual maturity between 2 and 4 years, while females reach it between 3 and 5 years (Sundelöf *et al.*, 2022). In some lakes where perch is the predominant predatory species, populations are referred to as “tusenbröder,” in Swedish or "thousands of brothers" (SLU, 2023a). This name is given because fierce competition for food resources and the scarcity of prey keep individuals at a small size (SLU, 2023a).

2.4 European directives

Thematically, the MSFD addresses ecosystem components beyond those included in the WFD (EC, 2003). Geographically, MSFD encompasses marine areas up to the limit defined by the WFD (Bergström *et al*, 2016).

The WFD is based on a straightforward ecosystem approach (Eur-Lex, 2014). Its main objectives are to preserve European waters and achieve good environmental status (GES). Ecological quality is assessed using Biological Quality Elements, BQE (Lindegarth, 2016). In European lakes, fish are among the BQE that are monitored to meet the requirements of the WFD. For lakes, the indicative parameters to be included in fish-related biological assessment methods are taxonomic composition, abundance, disturbance-sensitive taxa, and age structure (Holmgren, 2016). As perch is an important part of European lake fish communities, it is directly or indirectly included in many fish metrics used to assess the ecological status of lakes (Ritterbusch *et al.*, 2022). Coastal fish are not considered a BQE within the framework of the WFD (Bergström *et al*, 2016).

The MSFD aims to preserve the marine environment and its biodiversity in all EU member states (Vivienne Halleux, 2023) while consistent with an ecosystem-based approach to management (Probst *et al*, 2012). MSFD’s initial objective was to achieve the GES in EU marine waters by 2020, focusing on preserving resources vital to marine-related economic and social activities (EC, 2020). Three core descriptors, D1, D3, and D4 focus on fish populations. In Sweden, D1 and D4 involve perch to assess the health of the Baltic Sea (HELCOM, 2023a). The GES is achieved for these indicators when the size distribution of key species, represented by indicator L90, is above a specified threshold value (HELCOM, 2023a). Therefore, the length frequency distribution is essential for describing the fish stock's overall health (Probst *et al.*, 2012).

The D1, known as "Marine Biodiversity," focuses on the demographic characteristics of populations, such as body size, age structure, sex ratio, fecundity, and survival rates, to assess the health of species and their sensitivity to anthropogenic pressures. These assessments apply specifically to coastal fish species (HELCOM, 2023a). The D3, "Commercial fish and shellfish," assesses whether these populations remain within safe biological limits, with appropriate age and size distributions indicating a healthy stock (HELCOM, 2023a). The 95th percentile length metric, L95, is used to indicate critical status (Shin *et al.*, 2005). Then, the D4, "Food web, " focuses on the marine structure of marine food webs. Its approach considers the structure and function of food webs by compartmentalizing species that share common characteristics: trophic guilds. One of the main criteria is that anthropogenic pressures do not adversely affect the diversity of the trophic guild.

As an active EU state member, Sweden monitors fish in inland and transitional coastal waters. EU regulatory frameworks govern the Baltic Sea (MSFD) and lakes (WFD) to safeguard and improve the quality of aquatic environments. Sweden actively engages in conservation and monitoring efforts across its marine and freshwater systems. While methodologies and indicators for assessing environmental status vary among coastal areas and small and large lakes, a comparative analysis of perch size data is possible. This comparative study is facilitated by the shared goals of the EU directives that include fish metrics for monitoring populations and size distributions to assess ecological status.

3 Material and methods

3.1 Studied ecosystem

This section provides an overview of the Swedish aquatic systems studied: the Baltic coastal areas (Fig. 2) and inland lakes (Fig. 3 and Appendix 1). It also presents their current environmental status.

3.1.1 Swedish Baltic Sea coast

Figure 2. Map of Sweden (Sverige in Swedish) and its coasts with the Baltic Sea in light blue (Österjön in Swedish) (adapted from VISS, 2023).

The Baltic Sea is a semi-enclosed body of water covering 420,000 km^2 (HELCOM, 2018) with a water volume of 21700 km^3 (Kniebusch *et al.*, 2019) and a coastline of around 8,000 km (Carstensen *et al.*, 2020). The Swedish territory, which extends up to the Bothnian Bay, accounts for 140900 km^2 of the sea surface (VISS, 2023). The Baltic Sea is one of the largest brackish seas in the world (BSAG, 2023).

Only connected to the open sea via the Kattegat Strait, between Sweden and Denmark, the water exchange is limited (BSAG, 2023). The strait is a transition zone between the brackish Baltic and the marine North Sea. Despite its shallowness, seawater can take at least 30 years to fully exchange with the North Sea. These unique characteristics make it a crucial habitat for aquatic life (WWF, 2022).

Direct precipitation, numerous smaller rivers, and seven major rivers enter the sea (HELCOM, 2018) and supply freshwater, influencing the Baltic Sea's low salinity.

The coastal areas of the Baltic Sea are home to a concentrated community of fish mixed with marine and limnic species (Nilsson *et al.,* 2004). Coastal ecosystems are some of the most prolific and economically vital aquatic systems globally, yet they face escalating anthropogenic stressors (Olsson *et al*., 2012). These areas are susceptible to threats to their delicate balance and vitality. Fishing is one of the significant challenges facing the sea, along with eutrophication, hazardous and polluting substances, and climate change (HELCOM, 2023b). Other disruptions to spawning grounds, feeding habitats, and competitiveness between populations and other fish species have been significantly observed in coastal areas and river mouths, which are vital for the various life stages of fish (HELCOM, 2023b). Therefore, climate change, pollution, eutrophication, fishing mortality, exploitation of critical habitats, and natural factors such as food web interactions and predation influence the status of coastal fish species in the Baltic Sea (HELCOM, 2023a). It is assumed that the increasing impact of these factors has contributed significantly to the decline in coastal fish populations over the last 30 to 40 years (Hansson, *et al*., 2022).

The Baltic Sea is one of the world's fastest-warming marginal seas (HELCOM, 2023b). Indeed, global warming raises the air and water temperatures of the region (Kniebusch *et al.*, 2019), also resulting in higher average annual precipitation in the northern part (HELCOM, 2023b). As a result, more freshwater would enter the sea, reducing salinity. Nevertheless, no statistically significant trend in salinity was found, and future projections are highly uncertain. The frequency and duration of marine heat waves are also expected to increase, particularly in coastal areas (Kniebusch *et al.*, 2019). Thus, the Baltic Sea would warm, but its future salinity level has yet to be established. It is already known that climate-induced effects directly influence fish by altering recruitment success and growth rates or disrupting species distribution, prey availability, and ecological interactions (HELCOM, 2023b). Temperature and seasonal fluctuations influence the timing and duration of spawning seasons or zooplankton abundance during crucial stages of fish development (HELCOM, 2023b).

Last but not least, the Baltic Sea is often described as an environmental disaster (Elmgren *et al*., 2015) since it is usually considered one of the world's most polluted seas (HELCOM, 2010). The geomorphology and hydrological cycle of the Baltic Sea exacerbate the issue of eutrophication related to the discharge of nutrients from human activities (BSAG, 2023). Once excess nutrients from human-land activities pollute an aquatic environment, it is an ideal breeding ground for algae, contributing to anoxic areas (BSAG, 2023).

3.1.2 Swedish Lakes

Sweden counts almost 100,000 lakes, equivalent to nearly 9% of its surface area, or 40,000 km^2 (Larson, 2012). Of this number:

- 22 are larger than 100 km^2,
- 358 lakes are between 10 and 100 km^2,
- 3,990 are between 1 and 10 km^2.

Sweden's four largest lakes (Fig.3) are all located in the south of the country and share a similar latitude. Called the Great Lakes, they are Vänern, Vättern, Mälaren, and Hjälmaren in ascending order of surface area and volume (Table 1). To underline the importance of these lakes in terms of surface area, Vänern is the third largest lake in Europe, and Vättern is the 11th one (Larson, 2012).

Figure 3. The Sweden's four Great Lakes (adapted from Eklund et al., 2018, Fig 2, p5)

Table 1. Morphometric data on Sweden's four Great Lakes (based on Kvarnas, 2001, p468)

Lake	Surface (km^2)	Water volume (km^3)	Average depth (m)	Max. depth (m)
Vänern	5648	153	27.0	106
Vättern	1856	74	39.8	128
Mälaren	1096	14	12.8	63
Hjälmaren	484	3	6.1	22

The environmental impact on a lake can vary significantly depending on its geographical location, physical characteristics, and the combination and predominance of abiotic and biotic factors and human activities (Degerman *et al.*, 2001). In addition to fishing, fish populations are disrupted by physical, chemical, and biological impacts resulting from the construction of dams and navigation canals and eutrophication (Degerman *et al.*, 2001). Furthermore, detecting organic micropollutants, including pharmaceuticals, industrial chemicals, and PFAS, has become increasingly prevalent in Lake Mälaren (Rehrl *et al.*, 2020). These pollutants threaten aquatic ecosystems and contaminate drinking water and fish harvested from the lake. These pressures are exacerbated by densely populated communities and extensive agricultural districts surrounding the Great Lakes (Degerman *et al.*, 2001).

With global warming, lakes will continue to experience significant and pronounced changes in their ecosystems, particularly in rising temperatures, influencing phytoplankton production and nutrient cycling (Markensten *et al.,* 2010; Bergström and Karlsson, 2019). Rising temperatures and longer seasons will improve nutrient availability for phytoplankton, boosting lake productivity, and warmer winters will reduce ice cover (Markensten *et al.,* 2010). These changes will influence the geographic distribution of the current species. Such alterations will profoundly impact the lake's food web and organisms' behavioral and physiological adaptations (Woolway *et al.,* 2022). Research indicates that warmer lake temperatures generally decrease the average length of fish within the entire fish community (Emmrich *et al*., 2014).

Over the past 150 years, a notable deterioration of water and an increase in acid deposition (Fölster *et al.*, 2014) has presented a significant environmental challenge. In the last decades, there has been a decline in these deposits. Despite this positive trend, soil and aquatic ecosystem regeneration remains slow (Holmgren, 2014), primarily due to the compounding effects of climate change and land use practices in watersheds. To address these concerns, Sweden, through the Swedish Environmental Protection Agency (SEPA), has implemented a comprehensive, large-scale liming program to ameliorate the adverse impacts of historical and contemporary acidification (Fölster *et al.*, 2014). This initiative is designed to restore soil and water pH levels, thereby playing a pivotal role in preserving and restoring ecosystem integrity. Since the 1980s, acidification and liming have been focal points in the Swedish environmental restoration program (Holmgren *et al*., 2016). Acidification peaked around 1985 (Moldan *et al*., 2013). This heightened awareness has precipitated the establishment of meticulous monitoring protocols for fish communities and other ecological indicators across myriad small lakes nationwide (Holmgren *et al*., 2016).

3.2 Fish data sources

The Department of Aquatic Resources of Sveriges lantbruksuniversitet (SLU Aqua) hosts survey data on fishing activities in lakes, rivers, and coastal areas on behalf of the HaV. The purpose is to collect fishing data from commercial and recreational fishing activities, and data on fish communities as part of environmental monitoring. Fish monitoring is done nationwide, including rigorous measurement, quality control, secure storage, and updating. Data for this study were selected from two national fish databases: NORS (lakes) and KUL (coastal areas). They both include data from fish monitoring by gillnet sampling, including individual length, weight, sex, and age. These national databases are available online, making them publicly accessible.

3.2.1 Gillnet data for coastal perch

The multi-mesh Nordic coastal gillnet, known as the Nordic net, is the main gear in the coastal fish monitoring program (HELCOM, 2019). It consists of bottom-set gillnets that are 1.8 m (6 ft) deep and 45 m long. They are composed of 9 panels, each 5 m long, with 10-60 mm bar mesh sizes. Net fishing takes place between mid-July and mid-August. The monitoring program's smallest geographical unit is a station at which a gillnet is set. The sampling strategy is based on depth-stratified random sampling using up to 45 stations distributed in different depth intervals. A group of stations in the same depth interval (0-3 m, 3-6 m, 6-10 m, or 10-20 m) constitutes a section or area (HELCOM, 2019). Each station is subject to a yearly fishing effort.

3.2.2 Gillnet data for lake perch

The Swedish standard SS-EN 14757:2015 for fish sampling using Nordic multi-mesh gillnets is the same as the European standard (SIS, 2015). The standard involves benthic gillnets set over the whole lake in a random, depth-stratified design (sometimes also including pelagic gillnets). For Swedish conditions, sampling should be conducted in late summer, from mid-July to August. The Nordic benthic gillnet is 1.5 meters in height, comprising 12 panels, each 2.5 meters long, with mesh bar sizes ranging from 5 to 55 mm, known as Bnord12 (Holmgren, 2016). This method is designed to catch most fish species and size classes available in the lakes, and it is suitable for monitoring fish communities according to the WFD. The standard sampling effort (number of benthic gillnets) depends on the lake's surface area and the maximum depth, but the standard sampling of whole lakes is, in practice, best suited for smaller lakes. Catches are recorded in terms of numbers and biomass separately for each species (including perch) captured in every net. The length of each fish is measured for total length (in mm), with optional registration of the mesh size that captured the individual fish. For the Great Lakes, different types of benthic gillnets (including the coastal multi-mesh Nordic coastal gillnet) have been deployed across various depths within selected stations similar to coastal areas.

3.2.3 Selection of perch length data

For all three systems, individual length measurements of perch in gillnet catches were extracted from the national databases KUL and NORS, along with information on the coastal area and lake name, fishing gear used (and for lake mesh size), and year of sampling. Coordinates (projection WGS84) for coastal and small lake stations and those for large lakes (projection SWEREF99) were extracted from fish databases to explore the spatial gradients of L90.

For lakes, individual length measurements were extracted for all perch caught in Bnord12 in whole-lake samples in small lakes and with different gillnet types at subareas in the large lakes. Then, only perch caught in mesh sizes $\geq$ 10 mm in benthic gillnets were selected to get subsamples of the catches with size selectivity more similar to those from the coastal areas.

In the next step, only perch $\geq$ 15 cm were selected from each sample in all three systems. Research indicate that at this size, perch mainly adopts a piscivorous diet, thus assuming a role in the food web of its environment (Estlander *et al.*, 2010). This size threshold enables the targeting of the largest individuals while discerning the presence of other individuals of sufficient size who play a key role in the station's ecosystem, particularly in areas where the large fish population is not particularly abundant. It also reduces the effect of recruitment pulses that could influence L90 (HELCOM, 2023a).

This procedure did not reduce the number of available areas from coastal areas and large lakes, but among data from over 2000 small lakes, samples from only 163 lakes included recorded mesh size of the catch. This subsample of the total catch was used to calculate the number of individuals > 15 cm (Ntot). The L90 indicator was calculated as the size of the fish at the 90th percentile of the length distribution to illustrate the size of the largest fish in the population. The European Commission has proposed a 95th percentile length, but the 90th percentile is more appropriate for monitoring data on coastal fish (Östman *et al.*, 2023).

Initially, L90 was calculated for all sampled areas and years in the selected datasets, independent of Ntot. According to Östman (2023), at least 200-300 fish are needed per study station to get a statistically valid estimate of L90. Nevertheless, in the scope of this thesis, the certainty of the L90 value could be reduced because of significant heterogeneity in the number of perch caught in each coastal and lake area, sampling year, and too-low sample size (Östman *et al.*, 2023). Therefore, two criteria were set up to sort the data for further analysis:

1. For stations with less than or equal to two sampling years, the average number of individuals per year should be at least 100.
2. For stations sampled for at least three years, the average number of individuals per year should be larger than 50.

3.3 Initial data

Given the distinct systems studies, for clarity, a station or sampled area corresponds to a coastal station along the Baltic Sea, a subdivision within a large lake, and a whole small lake.

3.3.1 Coastal data

The initial data included 37 areas from the Swedish Baltic Sea coast, with a data collection period from 1987 to 2022. The data presented a wide range regarding the number of perch caught and the collection years. Indeed, the number of sampling years varied, depending on the station, from 1 year (Skellefteå) to 36 years (Kvädöfjärden).

3.3.2 Lake data

Data from each lake were associated with a sampled area. Within the dataset, a column entitled "*Lokalnamn*" specified the area sampled in the lake. For each data, the station was categorized as a small lake if the column referred to "*Hela sjön*" (the whole lake in Swedish). Conversely, any designation other than "*Hela sjön*" indicated that the lake had been segmented into multiple areas, classifying it as a large lake.

Large Lakes

The initial data included six distinct large lakes (Table 2), the four Great Lakes, and two others, Siljan and Storsjön, with data from 2000 to 2022. The data presented 36 distinct areas with a wide range regarding the number of perch caught and the collection years. Indeed, 23 large lake areas have been sampled once, whereas only two areas present seven non-consecutive collection years: Lake Mälaren (Prastfjärden) and Lake Vänern (Byviken).

Table 2. Number of sampled areas in each large lake

Large Lakes	Number of areas
Hjälmaren	4
Mälaren	9
Siljan	4
Storsjön	2
Vänern	6
Vättern	11

Small Lakes

The initial data included 163 small lakes, with data from 1994 to 2022. The data presented a wide range regarding the number of perch caught and the collection years. The number of sampling years varied, depending on the small lake, from 1 year (83 lakes) to 29 years (12 lakes).

3.4 Statiscal analyses

All data had to satisfy the above-mentioned conditions (in section 3.2.3) before being utilized for statistical analyses to address the study's questions.

Question 1

All data (sampling years and stations) were used to answer the first question to establish the average L90. Since the 2016-2022 dataset is a subset of all sampling years, data prior to 2016 for each system were also used. Descriptive statistics presented the central tendency, variability, and dispersion of L90 and Ntot (the number of individuals used for quantile calculations).

Main differences in variance were noted between periods, attributable to variations in the number of sampled stations prior to 2016 and during 2016-2022. Indeed, some stations were sampled in both periods, while others were unique to one period.

Therefore, a t-Welch test was performed to assess the difference in mean L90 and Ntot between each system’s two periods. This statistical method compares the means of two samples when their variances are unequal. For this question, by not assuming equal variances between the two periods, the t-Welch test offered a more reliable and robust assessment of the significance of L90 mean differences than a classical t-test or ANOVA.

Question 2

An ANCOVA statistical test was required to determine whether the mean L90 differed significantly between systems.

The data's normal distribution was assessed using the Shapiro-Wilk test. A histogram was generated since Mean L90 did not follow a significantly normal distribution. Although some data do not strictly follow a normal distribution, the deviation was considered relatively correct without transforming the data. Nevertheless, a robustness test was carried out to ensure the validity of the statistical analysis. To this end, an effect test was performed using "pwr" R package. The robustness of the observation of an effect was demonstrated significantly for an effect of 0.5. Consequently, an ANCOVA test was performed without data transformation.

Prior to this, a preliminary correlation test was necessary to select the covariate and avoid a multicollinearity effect. As the data did not follow a normal distribution, Pearson's correlation test, which relies on normality, could not be used. Instead, the Kendall's correlation test was employed. Kendall's test is a rank correlation tool and does not require normality, making it a reliable choice for our analysis. The results indicated that Num_Years was the covariate to include in the ANCOVA.

Then, the ANCOVA was performed to examine the mean L90 between the three study systems. In this linear model, the Mean L90 variable was studied as a function of the Category and Num_Years variables. Category, which corresponds to the three study systems, was treated as a categorical variable, and Num_Years as a continuous covariate.

At last, to determine which systems significantly differ in mean L90, a pairwise comparison was performed between systems using t-tests with pooled standard deviation. The Mean L90 and Category variables were analyzed. A Bonferroni adjustment method for p-values was chosen to reduce the bias of simultaneous comparisons between the different categories. In this adjustment method, the significance criteria are stricter to compensate for the multiplicity of tests.

Question 3

Scatter plots and bar graphs were generated with the calculated mean L90 of each sampled area and their latitudinal or longitudinal coordinates to observe a spatial gradient in each study system.

The standard error was preferred to the standard deviation for the graphical representation to estimate each station's mean precisely. While the standard deviation indicates the dispersion of the data around the mean, the standard error also considers each station’s sample size.

Question 4

The fourth question did not require statistical analysis. The scope of this study did not include data or environmental characteristics from the three system's sampled areas. Therefore, it was addressed through a comprehensive literature review of scientific articles on factors affecting perch size, growth, and L90.

3.5 R software

The version *R 4.3.1 GUI 1.79 Big Sur Intel build (8238), R pour Mac OS X Cocoa GUI par Simon Urbanek, Hans-Jörg Bibiko, Stefano M. Iacus, © 2004-2023, La Fondation R pour le Calcul Statistique http://www.R-project.org was used.* All analyses were conducted through RStudio, an integrated development environment with R. Posit Software PBC used version 2023.09.0+463 (2023.09.0+463) © 2022. Numerous packages have been downloaded for data processing and graphics; the main ones used were "*readxl*," "*gglplot2*," and "*ggpubr.*" Some R scripts are presented in the Annex.

4 Results

4.1 Average L90 of perch within systems

Coastal areas

For all sampling years, 34 areas fulfilled the criteria for inclusion (Table 3). Across all areas and collecting years, the mean L90 was 26.0 cm with a mean Ntot of 375 fish (Table 3 and 4). From 1987 to 2015, only 26 areas had sufficient sample sizes to be included. For this period the mean L90 was 25.6 cm, and the mean Ntot was 373 fish (Table 3 and 4). For 2016-2022, the number of areas included was 31 (Appendix 2), with a mean L90 of 26.1 cm and a mean Ntot of 380 fish (Table 3 and 4).

Table 3. Descriptive statistics on coastal L90 data

Period	Num. of areas	Mean L90	Median L90	Weighted Variance L90	SE L90
All years	34	26.0	25.5	5.8	0.2
1987-2015	26	25.6	25.0	2.6	0.2
2016-2022	31	26.1	26.0	7.3	0.3

The medians of L90 are slightly lower than the means (Table 3), which suggests a relatively symmetrical data distribution, with little effect of extreme values on the mean in either period. The data's dispersion was slightly larger for 2016-2022 than for 1987-2015, with a standard error of 0.3, a relatively precise dispersion estimate.

The distribution of Ntot showed a notable asymmetry, shown as a substantial difference between means and medians (Table 4), supported by a high weighted variance and high standard error. These results might be attributed to high Ntot heterogeneity between monitoring areas or collection years, extreme Ntot data, or a wide distribution of Ntot over the entire coastal system.

Table 4. Descriptive statistics on coastal Ntot data

Period	Num. of areas	Mean Ntot	Median Ntot	Weighed Variance Ntot	SE Ntot
All years	34	375	308	27780.2	13.7
1987-2015	26	373	326	23355.3	16.0
2016-2022	31	380	274	32356.4	16.1

According to Welch's test, there was no significant difference in mean L90 between the 1987-2015 and 2016-2022 periods (t = -0.683, Df=55, p = 0.50, Appendix 3). The result indicates that the minor mean differences between the two periods are not statistically significant at the 95% confidence level. The same pattern holds for the mean Ntot between both periods. The result indicates no significant difference at the 95% confidence level (t = -0.121, Df = 55, p = 0.90, Appendix 3).

Large Lakes

For all sampling years, 19 areas fulfilled the criteria for inclusion (Table 5). No areas or sampling years in Lakes Siljan and Storsjön met the inclusion criteria. Across all areas and collecting years, the mean L90 was 26.1 cm with a mean Ntot of 248 perch (Table 5 and 6). From 2008 to 2015, 17 areas fulfilled the conditions. The mean L90 across areas for this period was 25.5 cm, and the mean Ntot was 238 perch (Table 5 and 6). For 2016-2022, the number of areas included was 11 (Appendix 4), with a mean L90 of 27.2 cm and a mean Ntot of 313 perch (Table 5 and 6).

Table 5. Descriptive statistics on large lake L90 data

Period	Num. of areas	Mean L90	Median L90	Weighted Variance L90	SE L90
All years	19	26.1	25.3	2.3	0.3
2008-2015	17	25.5	25.0	2.1	0.3
2016-2022	11	27.2	27.8	1.5	0.2

The medians of L90 were lower than the mean during 2008-2015 and higher than the mean in 2016-2022 (Table 5). It could suggest that some "extreme" values were higher during 2008-2015 and lower for 2016-2022. This observation could be seen in the "All years" average, where the overall mean surpasses the median. Thus, the L90 values of 2008-2015 had a more substantial impact on the "All years" average than the low "extreme" values observed in 2016-2022. Regarding weighted variance and standard error, the results showed a relatively low dispersion about the mean, with accurate estimates of data dispersion.

There was a notable asymmetry in the distribution of Ntot, with a substantial difference between means and medians, supported by a high weighted variance and standard error (Table 6). These results might be attributed to high Ntot heterogeneity between sampled areas or collection years, extreme Ntot data, or a wide distribution of Ntot over the entire large lake system. In this case, many stations failed to meet the inclusion criteria, which could increase heterogeneity within a small number of sampled stations.

Table 6. Descriptive statistics on large lake Ntot data

Period	Num. of stations	Mean Ntot	Median Ntot	Weighed Variance Ntot	SE Ntot
All years	19	248	178	12046.8	20.1
2008-2015	17	238	180	3290.1	11.3
2016-2022	11	313	214	17388.8	27.4

According to Welch's test, there was a significant difference between the 2008-2015 and 2016-2022 periods in terms of mean L90 (t=-2.170, Df=25.99 p = 0.039, Appendix 5). The result indicates that the average of the 2016-2022 is significantly higher than the 2008-2015 average. Thus, there is a significant mean L90 difference between the two periods at the 95% confidence level. Nevertheless, for the mean Ntot between both periods, the result indicates no significant difference at the 95% confidence level (t = -0.834, Df = 13, p = 0.42, Appendix 5).

Because a large number of sampling areas did not meet the criteria for inclusion in the statistical tests, the initial L90 data were also explored by a graphical representation (Figure 4), to better understand the temporal and spatial variability within the Great Lakes and their sampling areas. The non-homogeneous collection years for sampling areas within and between the Great Lakes did not allow a clear interpretation of a trend, but some patterns could be deduced:

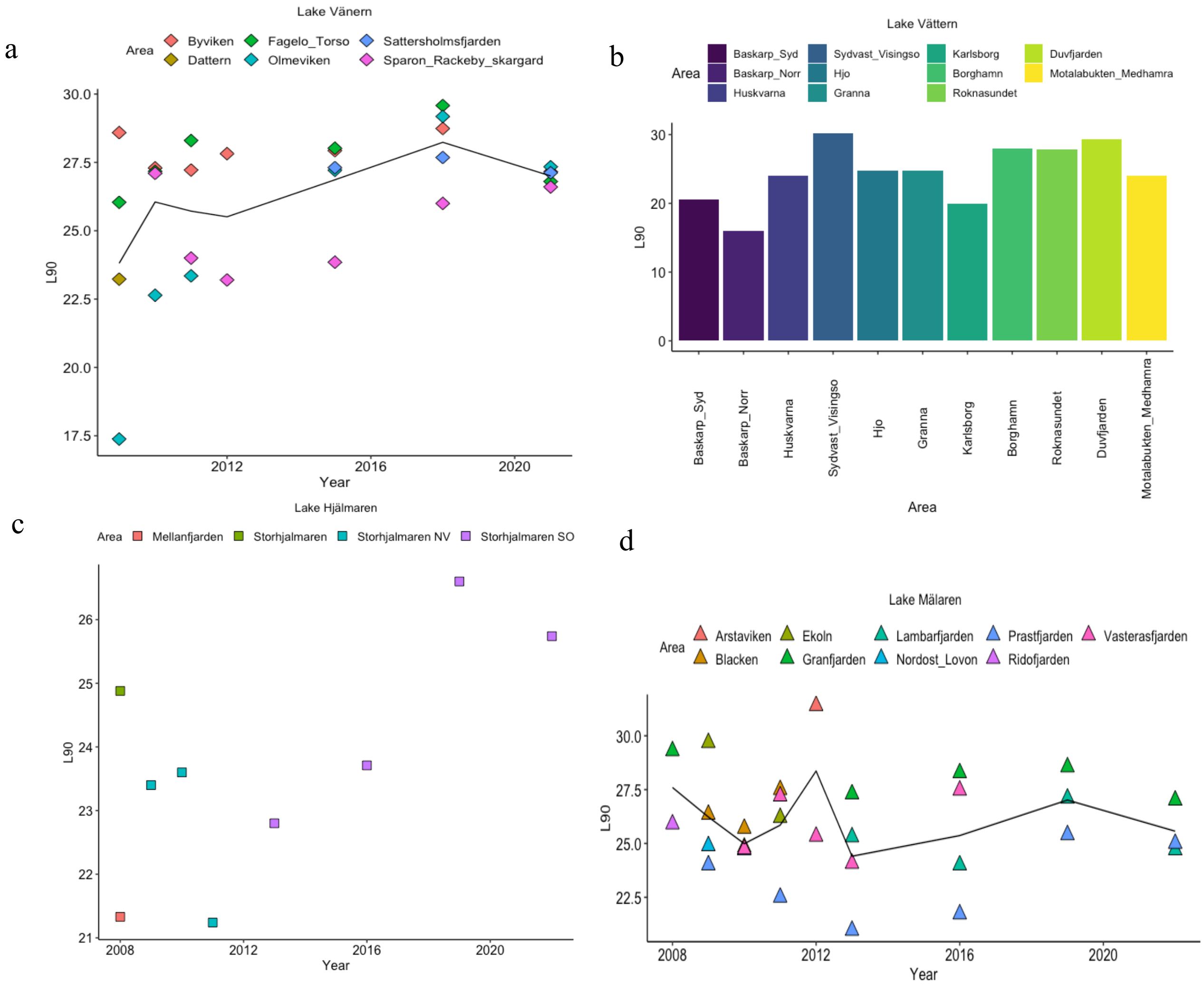


Figure 4. Temporal analysis of L90 across areas in (a) Vänern (2009-2021), (b) Vättern (2020), (c) Hjälmaren (2008-2022), and (d) Mälaren (2008-2022).

a) In Lake Vänern, there seems to be a trend of increasing L90 perch size over time across comparable areas (Fig.4a).
b) In Lake Vättern, there seemed to be no clear spatial differences in L90 across areas within the lake in 2020. Nevertheless, the two easternmost areas of the lake had the smallest L90 compared to the other areas (Fig. 4b).
c) In Lake Hjälmaren, the Storhjälmaren SO area suggested a steady increase in L90 between 2012 and 2018 (Fig.4c).
d) In Lake Mälaren, the average L90 trend across areas and collection years showed that comparable areas do not show substantial changes in L90 over time (Fig.4d).

Small Lakes

For all sampling years, 86 small lakes fulfilled the criteria for inclusion (Table 7 and 8). Across all lakes and collecting years, the mean L90 was 26.3 cm with a mean Ntot of 165 perch. From 1994 to 2015, 83 lakes were included. The mean L90 across lakes for these years was 26.1 cm, and the mean Ntot was 166 perch (Table 7 and 8). For 2016-2022, the number of lakes meeting the criteria for inclusion was 31 (Appendix 6), with a mean L90 of 28.7 cm and a mean Ntot of 177 perch (Table 7 and 8).

Table 7. Descriptive statistics on small lake L90 data

Period	Num. of small lakes	Mean L90	Median L90	Weighted Variance L90	SE L90
All years	86	26.3	25.5	6.68	0.2
1994-2015	83	26.1	25.4	1.67	0.2
2016-2022	31	28.7	28.3	4.35	0.3

Table 8. Descriptive statistics on small lake Ntot data

Period	Num. of small lakes	Mean Ntot	Median Ntot	Weighed Variance Ntot	SE Ntot
All years	86	165	134	2338.7	4.1
1994-2015	83	166	135	2538.4	4.56
2016-2022	31	177	156.5	848.6	3.7

The medians of L90 are slightly lower than the means (Table 7), suggesting that the data are slightly asymmetrical. It may indicate that some values are pulling the mean upwards. Nevertheless, the data distribution is relatively symmetrical, with little effect of extreme values on the mean, whatever the period. Data dispersion according to variance is relatively moderate, with a high level of confidence.

There was a notable asymmetry in the distribution of Ntot, with a substantial difference between means and medians (Table 8), supported by a high weighted variance and standard error. These results may be attributed to high Ntot heterogeneity between small lakes or collection years.

According to Welch's test, there was a significant difference between the 1994-2015 and 2016-2022 periods in terms of mean L90 (t=-2.625, Df= 49 p= 0.012, Appendix 7). The result indicates that the average of the 2016-2022 is significantly higher than that of the 1994-2015 period. Thus, there is a significant mean L90 difference between the two periods at the 95% confidence level. Nevertheless, for the mean Ntot between both periods, the result indicates no significant difference at the 95% confidence level (t = -0.528, Df = 50, p = 0.60, Appendix 7).

4.2 Comparisons of L90 between the systems

In the sample, the Shapiro-Wilk test showed that 2016-2022 mean L90 data was not normally distributed (W=0.960, p-value = 0.02).

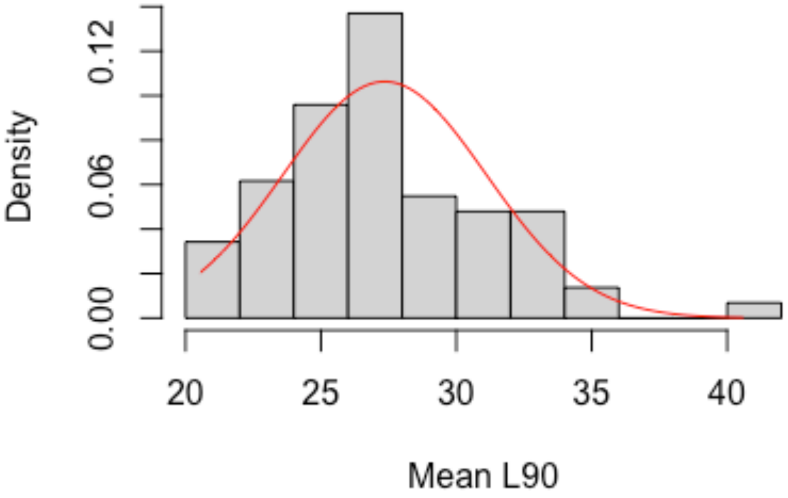


Figure 5. Distribution of mean L90 from the three study systems, with the normal distribution highlighted in red.

The histogram (Fig. 5) illustrates that the distribution of mean L90 data did not adhere strictly to a normal distribution. Within the range of 20-27 cm, the data exhibited some resemblance to a normal distribution, as evidenced by the alignment of the red curve. Nevertheless, within the mean L90-value of 27-37 cm, deviations from the normal distribution become more noticeable. Despite these variations, including an extreme value at 40 cm, the deviation from the red curve remained relatively proper globally. The data distribution maintained consistency and did not exhibit main distortion.

The statistical power of the ANCOVA test was determined based on the following parameters: a standard deviation of 4, 3 study groups, and a total sample size of 73. The calculated statistical power for the test was 0.99, indicating a confidence level of 99%, at a significance level of 0.05. Thus, it indicated a high probability of detecting a mean effect of 0.5 with an ANCOVA test under the defined parameters.

The three systems' 2016-2022 data showed no significant relationships between mean L90 and the number of sampling years (Kendall's z = -1.906, p = 0.06). The correlation is negative and moderate, but even if the p-value is slightly above the significant level, it is statistically not significant. However, a significant negative correlation was observed between the mean L90 and the mean Ntot (Kendall's z = -2.229, p = 0.03).

ANCOVA showed a significant difference between systems in mean L90 (Appendix 10, (F(2, 69) = 3.86, p = 0.026; Appendix 10). However, no significant difference was associated with the number of collection years ($F_{1,\,69}$ = 1.416, p = 0.24). Therefore, the result suggests that the different systems more strongly influence the variations observed in mean L90 than the number of sampling years.

The pairwise comparison showed a significant difference between the coastal and small lake systems (Table 9). Nevertheless, no significant difference was observed between the coastal and large lake systems, or between the small and large lake systems.

Table 9. P-values in pairwise comparison between systems 2016-2022 with Bonferroni adjustment

	Coast ***(31 areas)***	**Large Lake** ***(11 areas)***
Large Lake ***(11 areas)***	1.000	-
Small_Lake ***(31 areas)***	0.022	0.76

4.3 Spatial gradients of L90 within systems

Coastal area

Over 2016-2022, mean L90 varied considerably between monitoring areas along a gradient from south to north without any latitudinal trend (Fig.6). The highest L90 averages are concentrated at latitudes between 57 and 59 and longitudes between 17 and 19. The southernmost sampled area was Torhamn in Blekinge at a latitude of 56.08 (Appendix 2). The northernmost sampled area was Råneå, at a latitude of 65.8 (Appendix 2). The standard error of mean L90 within monitoring areas was often larger in the south than in the north (Appendix 8), partly because several southern areas were sampled in less than seven years during 2016-2022. Although the Kalmar län station had the highest mean L90, this mean value is not precise. In addition to only three annual samples, the high standard error of this station is influenced by a lower mean of Ntot compared with the other stations (2020: Ntot = 77, 2021: Not = 148, 2022: Ntot = 8). The central sampled areas Björnöfjärden and Älgöfjärden also had high mean L90 (close to 30 cm). Their L90 means were estimated with higher confidence. Further north, the average L90 varied between 22 and 29 cm.

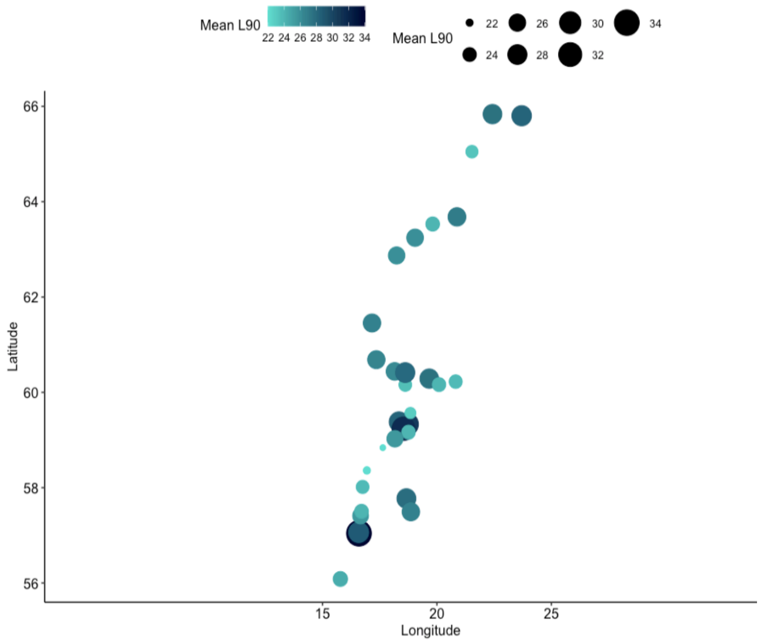


Figure 6. Scatter plot of mean L90 by latitude and longitude for the Baltic Sea coastal areas sampled in 2016-2022. The L90 average is represented by two indicators: color and dot size. The darker the color and the larger the dot size, the higher the average.

Large lakes

Table 10 gives an overview of the mean L90 by large lake. Few data met the inclusion criteria for analysis. Thus, a wide variation between the number of areas sampled per lake and the year of sampling is observed. For example, Lake Vättern has two sampling areas that were only sampled once. As for Mälaren, three of its four areas were sampled for 3 years, and one was only one year. For Hjälmaren, only one area was selected for analysis, and the sample was over three years. The variability in the data complicates the application of a test to assess the significant difference in L90 among the four Great Lakes. Nevertheless, the mean L90 varied between 25 and 30 cm depending on the lake in 2016-2022 (Table 10).

Table 10. Descriptive statistics on L90 data by large lake from 2016-2022

Lakes	Num. of areas	Num.of sampling years	Mean L90	Median L90	Weighed Variance L90	SE L90
Vänern	4	2	27.95	28.07	1.74	0.32
Vättern	2	1	28.59	28.59	*NA*	*NA*
Hjälmaren	1	3	25.35	25.74	2.2	*NA*
Mälaren	4	Max. 3	26.18	26.24	1.85	0.45

The westernmost station was Byviken in Vänern, and the easternmost station was Lambarfjärden in Mälaren (Fig. 7), had L90 values of 27.95 cm and 25.2 cm, respectively. Lake Vänern showed negligible variation within its areas, resulting in a relatively uniform mean L90 across the lake (Fig. 7). In the case of Vättern, the mean L90 also showed significant size in its two areas (Fig. 7). For Hjälmaren, the lowest mean L90 was observed at its only station. Finally, Mälaren revealed a divergence in mean L90 depending on the area sampled (Fig.7). In a broader perspective, the graph showed that the easternmost lakes, Vänern and Vättern, have mean L90 values consistently above 27 cm. Conversely, Lakes Hjälmaren and Mälaren have mean L90 values below this threshold, closer to 24-26 cm. Due to only one station for Lake Hjälmaren, it is uncertain whether this trend extends uniformly to the whole lake.

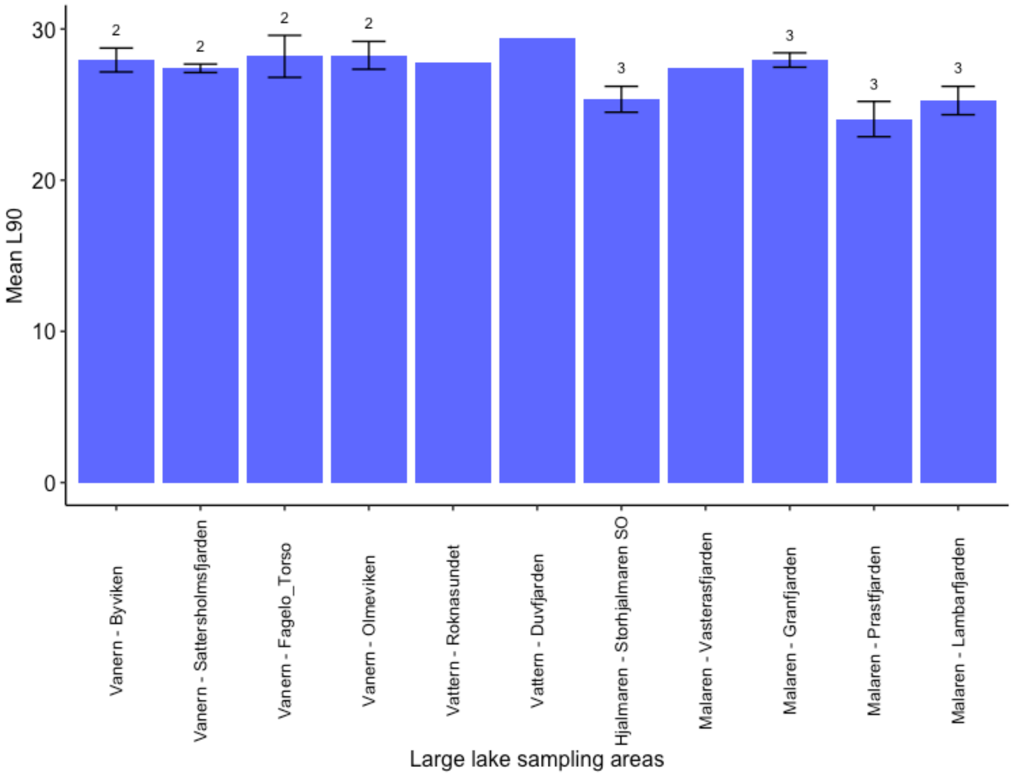


Figure 7. Vertical bar chart of the mean L90 according to the four Great Lake sampling areas in 2016-2022. The standard error and the number of collection years are shown for each station, except for those with only one collection year. Stations are ordered according to their SWEREF99 Easting coordinates along an east-west gradient (Appendix 4).

Small Lakes

Over 2016-2022, mean L90 varied considerably between small lakes, with no latitudinal and longitudinal trend (Fig. 8). The southernmost station sampled was Havgårdssjön, at latitude 55.48. The northernmost station sampled was Jutsajaure, at a latitude of 67.04 (Appendix 6). The highest value of the L90 mean appeared to be concentrated in stations at the latitudes of 57-61 and 62.5-65 (Fig. 8).

The standard error of the mean L90 within lakes was often wider in the south and the center of Sweden than in the north (Appendix 9), partly because several small lakes were sampled less than seven years or influenced by a lower mean Ntot compared with the northern small lakes. Despite geographic proximity, several small lakes presented different L90 means, from 25 to 40 cm. It is particularly notable that between latitudes 59-61, where only Dagarn has a high mean L90 (close to 30 cm) estimated with high confidence. Although the Lake Hjärtsjön station had the highest mean L90, this value is not precise since it was sampled only once. Further north, the average L90 ranged between 25 and 33 cm.

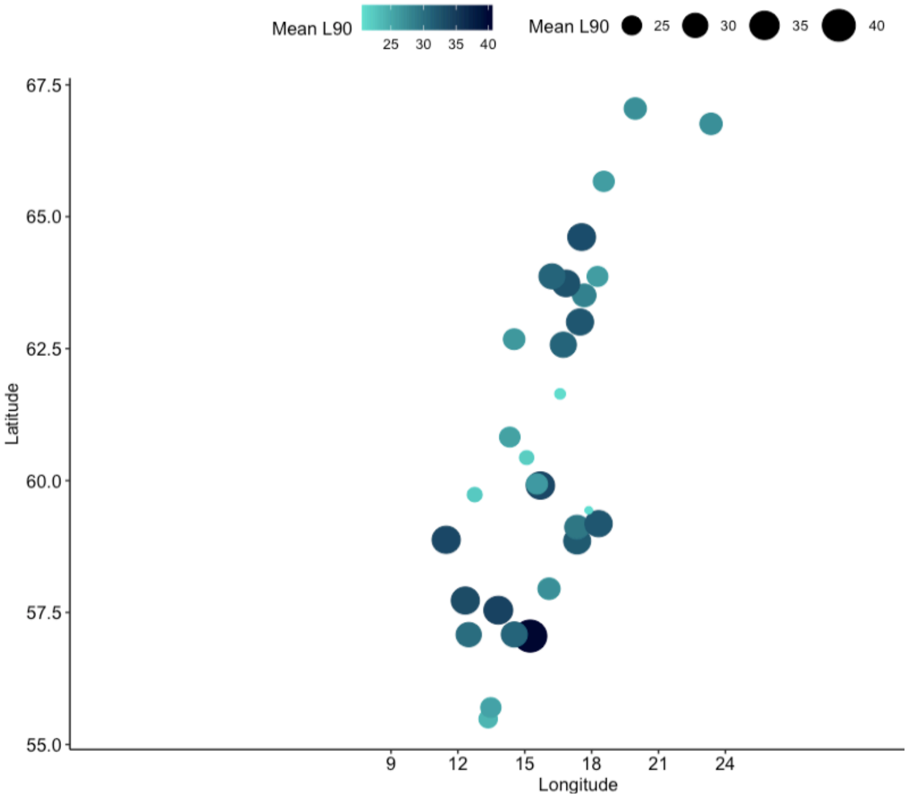


Figure 8. Scatter plot of mean L90 by latitude and longitude for small lakes sampled in 2016-2022. The L90 average is represented by two indicators: color and dot size. The darker the color and the larger the dot size, the higher the L90 mean.

5 Discussion

The results presented in this thesis revealed several new and significant findings since comparisons of L90 between coastal, large, and small lakes were made for the first time. The L90 was previously described as useful in indicating the occurrence of larger fish in coastal areas (Östman *et al*., 2023; HELCOM, 2023a). In recent years, it has been used along with other indicators in the Swedish stock assessment of perch and other coastal species, for which the Swedish fishery is managed nationally (SLU, 2023b). L90 was also used in national fish stock assessment in each large lake, but there is no similar stock assessment program related to fishery in the numerous small lakes of Sweden. The new results of the present study indicated that L90 increased over time in the large and small lake systems, that the size was significantly different between small lakes and coastal areas, and that differences at the local level in the average L90 exist within systems.

In the main study period 2016-2022, the average size of large perch in Sweden varies between 26.1 cm and 28.7 cm depending on the system, with an overall average of 27.3 cm for the three systems studied. These values were slightly higher than the average values calculated for all previous sampling years, with significantly higher values in the latter period for both large and small lakes. Our result shows that the average L90 for small lakes is the highest among the three systems studied. The most recent national stock assessment (SLU, 2023b) shows a time series of annual L90 and gives median L90 values during 2016-2022 for various areas in the coastal system. The focus on local areas is essential in assessing small-scale population structures. However, estimates of overall mean and standard errors are needed for large-scale comparison of coastal areas with other systems, e.g., with large or small lakes. Our results are consistent with a recent assessment by HELCOM (HELCOM, 2023a). This report mentions that the absence of consistent regional trends for L90 suggests a general lack of deterioration in the size distribution of perch in the Baltic Sea.

L90 variation in large lakes showed a positive development between the prior-to-2016 and post-2016 periods, as used in this thesis. In Vänern and Vättern the average L90 was close to 28 cm, while in Hjälmaren and Mälaren, it approached 26 cm. These variations correlated with the findings of the Fiskbarometern report (SLU, 2023b). Indeed, Lake Vättern showed the highest L90 value. In contrast, Lake Hjälmaren has the lowest L90-value across large lakes, indicating that large perch are smaller in this lake. However, the Fiskbarometern report suggests that this trend could be qualified by the strong year classes in 2018 and 2022 (SLU, 2023b), highlighting the need to integrate other indicators, such as L10 and L50, to interpret the mean L90 of 25.35 cm. For Lake Mälaren, the L90 is rather low, suggesting that large perch are also smaller in this lake. Finally, Lake Vänern presented a high average L90 over the four monitoring areas, but its data required an interpretation because of its depth since different sampling methodologies need to be used: two different nets (SLU, 2023b). Therefore comparing it with the other Great Lakes is difficult. Despite this aspect, fluctuations in L90 over time have been observed, varying according to the methodology used. Overall, all the Great Lakes exhibit a positive trend in L90 over time, indicating a favorable condition for perch. Only Lake Hjälmaren appeared to have a lower density of large perch than the other lakes (SLU, 2023b). Nevertheless, recent data on perch stocks suggest that perch populations in the four Great Lakes seem to be maintained within biologically safe limits (SLU, 2023b).

For the small lakes, this was the first analysis using the L90 indicator. As the number of fish caught in many lakes was below the threshold (≥ 15cm) for data inclusion, only a small subset of all lakes available was included in the analysis. For 2016-2022, 31 small lakes were analyzed. It represents less than 2% of the approximately 2,000 Swedish small perch lakes included in the NORS database. Although the L90 metric indicator is commonly used to assess the ecology of coastal areas and large lakes, its application to assess ecological status is not applied since it is not a WFD criterion (EC, 2003). Nevertheless, the study carried out by Holmgren and Petersson (2023) has provided a better understanding of the size of large and very large perch (>350 mm) and their prevalence in this ecosystem. Their findings highlighted a progressive increase in the occurrence and proportion of very large perch, including large perch, observed in northern and southern Sweden over time. Of the 2121 lakes sampled between 1996 and 2021, 55% recorded the capture of at least one very large perch, representing, on average, 1.2% of the total perch catch (Holmgren and Petersson, 2023).

Therefore, in addition to the significant difference in L90 found between systems 2016-2022, small lakes stand out as the only system with populations of very large perch, suggesting favorable and better conditions conducive to increasing L90 and the presence of large individuals throughout Sweden (Holmgren and Petersson, 2023). Therefore, the study's result underlines that perch in the open coastal system might experience a more significant and stronger palette of impacting pressures than the system of more isolated inland lakes. Nevertheless, it is essential to compare the L90 values with the Ntot, which provides information on the degree of certainty. The indicator was calculated for coastal areas with a Ntot average of 300 individuals and a relatively similar median, indicating a substantial amount of perch above the threshold value we selected (>15cm). On the other hand, large lakes, with a Ntot average of 250-300 individuals, also showed a good amount of large specimens. Finally, small lakes, with a Ntot average of less than 200 individuals, had a median of around 150, suggesting a small amount of large perch. The lower mean Ntot can be attributed to the sampling of small lakes with fewer gillnets per sampling event and the challenge of capturing larger fish. Additionally, lakes with dense juvenile and adult perch populations below the chosen 15 cm size threshold may also exhibit low mean Ntot. Nevertheless, having a small mean Ntot does not necessarily mean a low proportion of large perch in the catch and population density. Usually, the Catch per Unit Effort (CPUE) index is used for this purpose. Therefore, a low mean Ntot in a small lake does not necessarily mean a low CPUE.

An L90 value of 25 cm (SLU, 2023b) is considered an appropriate reference level for large fish to determine GES in coastal areas (HaV, 2020b). Therefore, the L90-

value, 26.1 cm, was above this L90 threshold value (HaV, 2020b). For the lakes, L90 is not part of the WFD criteria to determine their good ecological status. Nevertheless, the results of our study suggest that L90 can be applied in all aquatic systems, even for small lakes (a small subset of them), since at the system scale, only a slight variation in L90 was observed (HELCOM 2023a; Holmgren and Pettersson 2023, SLU 2023a). For future studies, it will be interesting to determine whether a different L90 size threshold value (> 25 cm) should be distinct regarding the system. In addition, for small lakes, it would be highly relevant to determine whether all lakes with good ecological status according to the WFD assessment are also assessed as having a good status for the L90 indicator. Indeed, although this is not a WFD criterion, a correlation would be interesting to observe, given the biological importance of perch and large individuals in the food web.

In our analysis, the number of exploitable data have been reduced to limit bias. However, spatial gaps exist along the coast, in large and small lakes. These gaps are related to station sampling or the regularity of sampling years. The spatial coverage of monitoring should be improved in certain areas to ensure the assessment data. No latitudinal trend in L90 was detected in the three systems due to the local difference in mean L90 between sampled areas within a system. Therefore, it may suggest that L90 of perch does not necessarily vary on a regional scale but mainly locally, independently of the system studied. Comparing this observation with the scientific literature proved difficult, as this topic has not yet been addressed. Nevertheless, the HELCOM 2023 report presents the L90 in different areas of the Baltic Sea and reveals regional variations. In Bothnian Bay and the Quark, conditions were generally poor, with exceptions in Finland (HELCOM, 2023a). The condition of the Bothnian, Åland, and Archipelago Seas was mainly good, but a few sites showed poor status. In the northern Baltic Sea, conditions were poor in Sweden and good in Finland. The overall status of the Gulf of Finland was poor, mainly due to specific sites (HELCOM, 2023a). In the Gulf of Riga and the western Gotland basin, status is variable but generally poor. In the more southerly parts of the Baltic Sea, perch status is consistently poor, except at one site in Poland (HELCOM, 2023a).

In our analysis, a coastal monitoring area was considered a sampling unit equivalent to a large lake area and to a whole small lake. This comparative approach was instrumental in facilitating the comparison between the systems. Nevertheless, they gather different types of ecosystems with different physicochemical and geomorphological parameters. Indeed, out of the three, the small lakes are considered a system of more isolated stations with more or less physical barriers to other areas. In contrast, the large lake and coastal areas sampled are connected as open systems with no apparent physical barriers that allow some individually tagged perch to migrate 10-20 km from the site where they were originally caught (Böhling and Lehtonen, 1984). From this perspective, the main differences observed in mean L90 between the geographically close monitoring areas raise questions about the underlying explanatory factors. Although this study did not explore environmental variables, it is plausible that the areas sampled, whether coastal or large lake monitoring areas, share similar ecological characteristics and comparable anthropogenic pressures due to their geographical proximity. For instance, fishing is generally open in coastal and large lake systems, while a permit is required for small lakes. This aspect could partly contribute to the variations observed at a local scale. Also, coastal ecosystem variability is influenced by factors such as the impact of fish migration from the offshore area and predation by marine mammals, a dynamic absent in lakes. Despite these variables, it is scientifically known that perch tend to be local, contributing to explaining L90 differences. Indeed, genetic analyses within lakes (Bergek and Björklund, 2007; 2009) and coastal areas (Olsson *et al.*, 2011) have shown that perch are predominantly stationary fish and that stocks are local. Therefore, if perch are a local species, a question may arise as to why research should continue to study them at the system level. One answer that could be given is that having an overview of conditions within and between different systems is essential to know all the mechanisms involved. This is even more essential when studying regional factors that affect all systems, such as climate change. Nevertheless, for stock management, it would not be always necessary to calculate the L90 at the system level depending of the research. On the contrary, a local study of the population and environmental pressures would be necessary to understand the small-scale variation.

Various factors, including regional and local conditions, are expected to influence large perch size. Nevertheless, only one research specifically addressed factors impacting L90-value. In their study, Östman *et al.* (2023) highlighted the correlation between increased fishing pressure and reduced L90, emphasizing the complex relationship between anthropogenic factors and perch size distribution. Although not directly addressed in this study, it is crucial to consider the conditions that lead to a large L90 size. Large perch in a system or on a smaller scale indicates that perch have thrived in conditions conducive to their growth and survived despite natural predation, fishing, and human activities. Scientific literature has discussed the impact of abiotic and biotic factors on perch size.

The systems studied in this thesis are all subject to global warming, which influences ecosystems differently in addition to increasing temperatures (HELCOM, 2023b). The coastal system will be more subject to marine heat waves (Kniebusch et *al.*, 2019), affecting seasonal fluctuations, species cycles, and zooplankton abundance during crucial phases of fish development. As for lakes, phytoplankton production and nutrient cycling will be impacted (Markensten *et al.*, 2010; Bergström and Karlsson, 2019), modifying the food web and the behavioral and physiological adaptations of organisms (Woolway *et al.*, 2022).

Warmer air and water temperatures have a significant influence on fish size. Indeed, with increased temperature, fish commonly show higher growth rates and a decrease in adult size (Atkinson, 1994), which would be presumed for perch (Mustamäki *et al.*, 2020). However, while this effect may be noticeable in juveniles and small specimens, adult body size may remain relatively stable despite increased growth over successive generations (Huss *et al.*, 2019). High water temperatures positively influence species' reproductive success, as for perch since they breed during the spring and summer months (Böhling *et al.*, 1991; Kokkonen *et al.*, 2019). Water browning, resulting from climate change and eutrophication with intensive land use, significantly impacts aquatic ecosystems (van Dorst *et al.*, 2019). The light limitation caused by browning can have adverse effects, altering resource composition and availability and negatively impacting vision-dependent fish like perch foraging. Browning water is also associated with increased chlorophyll a concentrations, shifts in zooplankton community composition, and reduced body growth rates for perch (van Dorst *et al.*, 2019). This reduced body growth in brown water primarily stems from resource availability and composition changes, compounded by reduced prey visibility. Similar observations regarding body growth have been made in coastal waters (Böhling *et al.*, 1991).

Natural predation could impact at a local level, encompassing specific prey-predator dynamics such as perch consuming other perch or the broader spectrum of predators impacting perch populations. Even though perch is a freshwater fish, the literature review on natural predation in lake ecosystems is limited. Coastal areas, on the other hand, present notable predation dynamics, notably by seals and cormorants, whose populations have surged since the 1980s (Dieterich *et al.*, 2004). Research carried out in the Baltic Sea indicates that perch are a frequent feature of the diet of these two predators. Cormorant predation, in particular, can significantly influence perch populations in localized areas. Fishing is responsible for around 36% of perch mortality in the Baltic Sea (SLU, 2023b), while birds contribute 51% (with cormorants accounting for almost 40% of bird predation) and seals 13% (Östman *et al.*, 2012). However, detailed and current data on the presence, feeding preferences, and consumption rates of perch by seals and cormorants in different coastal regions and the subsequent impact on perch stocks still need to be explored (Östman *et al.*, 2012). In the scope of L90, larger perch are likely to be more attractive prey for these predators. Therefore, cormorants and seals intensify the pressure on the larger specimens, increase their mortality rate, and reduce the average L90 value.

Finally, large perch are targeted by small-scale coastal commercial fishing and recreational fishing (Olsson et *al.* 2015), with the recreational sector dominant in some Baltic Sea countries (HELCOM 2015). The share of large perch in a population is affected by fishing pressure in an area and increases in marine protected areas (Östman *et al.*, 2023). Thus, lower mean values of L90 observed along the latitudinal axis in the thesis could signify a high mortality rate and significant fishing pressure at the system's local scale. While the perch is not endangered, regulations prohibit fishing in certain areas, but no minimum size are specified for perch fished in the Baltic Sea. For example, in the coastal waters of Gotland County, Kalmar Strait, and Öland, perch fishing is prohibited between March 1 and May 31 (HaV, 2021). Several protected areas have also been established along this coastline, stretching from northern Uppsala County to Kalmar County. In Norrbotten and Västerbotten counties, net fishing in shallow waters is prohibited from April 1 to June 10 and October 1 to December 31 (HaV, 2021). Similarly, in Västernorrland, Gävleborg, and north of Uppsala, this ban extends from September 1 to June 10, with a total ban on net fishing at all depths between October 15 and November 30 (HaV, 2021).

Despite the crucial economic and social roles played by commercial and recreational fishing in the three systems studied, there remains a notable lack of data concerning temporal trends in recreational fishing for large perch (SLU, 2023b). Recreational fishing, often considered a leisure activity, exerts significant pressure on aquatic fauna. HaV defines recreational fishing as any fishing activity that does not require an official permit. Perch is the most common target species for inland, coastal and marine fishing. In 2022, around 1.2 million Swedes took part in recreational fishing. The total catch (all species) amounts to 11,300 tons, including 8,500 tons from lakes and rivers and 2,800 from coastal and marine areas (HaV, 2023). The total number of catches released amounts to 16,500 tons, of which 12,500 tons are from lakes and rivers, and 4,000 tons are from coastal and marine areas (HaV, 2023). Therefore, over time, there may have been a change in behavior among anglers, who now practice catch-and-release, which would avoid removing large specimens from the environment (Sass and Shaw, 2020). Nevertheless, even if recreational fishing contributes more to perch catches than commercial fishing, significant catch-figure uncertainties complicate accurate assessments (SLU, 2023b).

In addition, tourism and commercial development in coastal systems and large lakes impact the perch's fragile habitats (Sundblad and Bergström, 2014). Activities like jetty and marina expansion, dredging, and other coastal construction affect shallow, sheltered bays (Sundblad and Bergström, 2014). From 2000 to 2022, perch catches in the Baltic Sea averaged 95 tonnes, with lows of 68 tonnes in 2009 and 86 tonnes in 2022. Although perch catches were mainly concentrated in the Bothnian Sea until 2015, they have been more evenly distributed across the Baltic Sea regions (SLU, 2023b). During the 20th century, commercial perch fishing was more intensive in the Great Lakes, with perch often caught as by-catch in commercial fisheries using bottom-set nets for pike-perch. Commercial perch landings in these lakes have declined from 250 tonnes in 1997 to 75 tonnes in 2022 (SLU, 2023b). In small lakes, recreational fishing and anglers' desire for trophy fish strongly influence L90. However, as the results of this thesis underline, this system offers favorable growing conditions for larger specimens (Holmgren and Petersson, 2016). Consequently, the population size distribution and mean L90 of a perch population indicate fishing pressure in the monitoring area. Nevertheless, collecting and consolidating the data gap on recreational fishing would be important to improve the overall understanding of perch fishing pressure and its significant impact on L90 indicator.

6 Recommendations for future studies

This research has presented numerous patterns for large perch in three distinct aquatic systems, paving the way for new avenues of research. To better define and understand the factors that ensure the development of large perch size, future studies should consider the following points:

As part of a comparative study, it is essential to emphasize the need to adopt a whole-system and interconnected approach to data collection in the three systems studied. For example, a whole-system sampling method should be implemented for large lakes to ensure that future data encompasses all areas in the same collection year. Indeed, the monitoring areas of large lakes and coastal systems are interconnected due to the absence of physical boundaries between them. Restricting sampling to a single area, as if isolated from the others, is detrimental to capturing and interpreting observed trends to know whether they are unique or generalized to the whole system. Adopting such an approach and maintaining the regularity of data collection efforts across the three systems can significantly improve data reliability and robustness despite differences in sampling protocols. It would also improve the interpretation of the result and the ability to discern trends at different scales. For field or budgetary reasons, it would be interesting to designate specific monitoring areas in the three systems as "reference" stations based on geolocation criteria or the presence of a high mean L90 population.

In this thesis, environmental data were not used to explain the variation in mean L90 within and between systems. Although the NORS and KUL databases contain characteristics specific to certain sampled areas (such as depth, Secchi disks, temperatures, and altitude above sea level for lakes), the data are not always directly comparable between the three systems since the monitored environmental variables vary from one system to another. Furthermore, a lack of knowledge and data on the local fishing pressure and natural predation hinders a comparative study of the most influential environmental variables between systems.

For future studies, incorporating some parameters in research could assist in better understanding L90 patterns. For instance, it could be a comparison of CPUE and L90 or on sex, since perch present sexual dimorphism in which females grow significantly faster than males. Adult females are larger and bigger. An analysis would certainly confirm the predominance of the female sex in the L90 perch population. Therefore, it would be interesting to compare inter- and intra-system perch populations, which share a similar mean L90, to investigate whether the female/male ratios are similar despite the systems.

In addition, a study of the L90 perch population in different countries and regions around the Baltic Sea can help determine whether lake systems offer better conditions than coastal areas and whether local geographical conditions influence size differences.

7 Conclusion

Although the perch is not classified as a threatened species in Sweden, its ecological and economic importance ensures its population monitoring. Because of its wide distribution, the perch has proved to be a relevant model species for studying and comparing L90 in coastal, large lake, and small lake ecosystems in Sweden. The study revealed an increase in mean L90 over time in large and small lake systems and differences at the local level within the three systems. A significant difference in size between coastal areas and small lakes was found, suggesting that the lakes provide better conditions for L90. Through its holistic approach, this study has highlighted the need for future research on large perch to understand better how environmental, genetic, and anthropogenic factors influence the size of large perch.

While the L90 averages for 2016-2022 were quite similar across the systems, differences in some sampled areas underscore the need for regional and local perch monitoring. Similar averages suggest similar large-scale conditions on aquatic systems, while local differences highlight the importance of studying small-scale impacting factors. These may vary considerably from area to area and system to system, emphasizing the need for comprehensive data collection. Although the L90 has proven to be an effective indicator for showing the status of perch in coastal areas and large lakes, it is less applicable due to data limitations for small lakes. Indeed, the total abundance of perch in certain lakes is significantly lower than in other systems. Thus, future research could focus on what indicator is best suitable for studying the size of large perch in small lakes. Another issue for future studies is to derive potential threshold values for L90 across systems. Should it be the same or different along coasts, in large lakes, and small lakes? Also, on a local scale, should threshold values vary within the system, depending on abiotic and biotic conditions in the different water bodies within each system?

Several actions can be considered to improve the understanding of large perch:

- Firstly, the three systems studied should be regularly sampled, focusing on the same environmental variables as system productivity. Also, continue to monitor commercial fishing on a regional and local scale and important impact factors rarely documented, such as local fishing, natural predation, and habitat characteristics, to study patterns and ensure effective management.
- Then, select populations in the three systems with similar average L90 to document, study, and compare habitat characteristics, population genetics, CPUE, abiotic and biotic conditions, local pressures, and human activities.
- Finally, closer collaboration with private lake owners and recreational anglers holds the promise of significant insights. The public and private nature of aquatic ecosystems in Sweden complicates coordination and monitoring responsibility. One solution is the introduction of national regulations mandating recreational anglers to provide detailed data on their catches to help create a shared database, facilitating a better understanding of the impact of fishing on perch size.

References

Adolfsson, P. (2010) ‘The Creation of New Ways of Acting in the Water Administration Field – the Implementation of the EU-WFD in Sweden’, in *Survival and Sustainability*. Berlin, Heidelberg: Springer Berlin Heidelberg (Environmental Earth Sciences), pp. 707–717.

Arranz, I. *et al.* (2016). 'Density- dependent effects as key drivers of intraspecific size structure of six abundant fish species in lakes across Europe'. C*anadian Journal of Fisheries and Aquatic Sciences,* 73, pp.519–534.

Atkinson, D. (1994) ‘Temperature and Organism Size—A Biological Law for Ectotherms?’, Advances in Ecological Research, 25, pp. 1–58.

Barnett, L.A.K. *et al.* (2017) ‘Old-Growth Fishes Become Scarce under Fishing’, *Current biology*, 27(18), pp. 2843-2848.e2.

Bergek, S. and Björklund, M. (2007) ‘Cryptic barriers to dispersal within a lake allow genetic differentiation of Eurasian perch’, *Evolution*, 61(8), pp. 2035–2041.

Bergek, S. and Björklund, M. (2009) ‘Genetic and morphological divergence reveals local subdivision of perch (*Perca fluviatilis* L.)’, *Biological journal of the Linnean Society*, 96(4), pp. 746–758.

Bergström, L. *et al.* (2016) ‘Coastal fish indicators response to natural and anthropogenic drivers–variability at temporal and different spatial scales’, *Estuarine, coastal and shelf science*, 183, pp. 62–72.

Bergström, A. and Karlsson, J. (2019) ‘Light and nutrient control phytoplankton biomass responses to global change in northern lakes’, *Global change biology*, 25(6), pp. 2021–2029.

Bianchi, G. *et al.* (2000) ‘Impact of fishing on size composition and diversity of demersal fish communities’, *ICES journal of marine science*, 57(3), pp. 558–571. Available at: https://doi.org/10.1006/jmsc.2000.0727.

Böhling, P & Lehtonen, H 1984, 'Effect of environmental factors on migrations of perch (*Perca fluviatilis* L.) tagged in the coastal waters of Finland ', Finnish Fisheries Research, vol. 5, pp. 31-40 .

Böhling, P, *et al.* (1991) 'Variations in year-class strength of different perch (*Perca fluviatilis*) populations in the Baltic Sea with special reference to temperature and pollution', *Canadian journal of fisheries and aquatic sciences*, vol. 48, no. 7, pp. 1181-1187.

BSAG (2023) The Baltic Sea - The World's Youngest sea, [online] Available at: < https://www.bsag.fi/en/the-baltic-sea / > [Accessed 7 Jan. 2024]

Carstensen, J. *et al*. (2020) 'Factors regulating the coastal nutrient filter in the Baltic Sea', Ambio, 49(6), pp. 1194–1210.

Cohen, J. E. *et al*. (1993) Body Sizes of Animal Predators and Animal Prey in Food Webs. The Journal of animal ecology. [Online] 62 (1), 67–78.

Christensen, E. A. F. *et al* (2020). The combined effect of body size and temperature on oxygen consumption rates and the size-dependency of preferred temperature in European perch *Perca fluviatilis*. J Fish Biol, 97, 794–803.

Chrysafi, A. *et al.* (2021) 'Effects of passive integrated transponder tags on short-term feeding patterns in European perch (*Perca fluviatilis*)', *Journal of fish biology*, 99(6), pp. 2035–2039.

Craig, J.F., 2000. Percid fishes: Systematics, Ecology and Expoitation. Blackwell Science, Oxford, UK. 368pp.

Cresswell, A.K. *et al.* (2019) 'Disentangling the response of fishes to recreational fishing over 30 years within a fringing coral reef reserve network', *Biological conservation*, 237, pp. 514–524.

Degerman, E. *et al*. (2001) 'Human Impact on the Fish Diversity in the Four Largest Lakes of Sweden', Ambio, 30(8), pp. 522–528.

Dieterich, A. *et al*. (2004) 'Competition for food between Eurasian perch (*Perca fluviatilis* L.) and ruffe (*Gymnocephalus cernuus* [L.]) over different substrate types', *Ecology of freshwater fish*. Accepted for publication April 7, 2004, 13(4), pp. 236–244.

Donadi, S. *et al.* (2017) 'A cross-scale trophic cascade from large predatory fish to algae in coastal ecosystems', *Proceedings of the Royal Society. B, Biological sciences*. Royal Society (Great Britain), 284(1859), pp. 1–10.

van Dorst, R.M. *et al.* (2019) 'Warmer and browner waters decrease fish biomass production', *Global change biology*, 25(4), pp. 1395–1408.

van Dorst, R.M. *et al.* (2020) 'Does browning-induced light limitation reduce fish body growth through shifts in prey composition or reduced foraging rates?', *Freshwater biology*, 65(5), pp. 947–959.

Eklund, A. and *et al.* (2018). *Sveriges Stora Sjöar Idag och I Framtiden*. [online] SMHI. Available at: https://www.diva-portal.org/smash/get/diva2:1180535/FULLTEXT01.pdf [Accessed 28 Dec. 2023]. ISSN: 1654-2258 © SMHI.

Elmgren, R., Blenckner, T. and Andersson, A. (2015) 'Baltic Sea management: Successes and failures', AMBIO, 44(3), pp. 335–344. Available at: https://doi.org/10.1007/s13280-015-0653-9.

Emmrich, M. *et al.* (2014). Geographical patterns in the body-size structure of European lake fish communities along abiotic and biotic gradients. Journal of Biogeography, 41, 2221–2233.

Estlander, S. *et al*. (2010) 'Diet shifts and food selection of perch Perca fluviatilis and roach Rutilus rutilus in humic lakes of varying water colour', Journal of fish biology, 77(1), pp. 241–256.

Estlander, S. *et al*. (2012) 'Troubled by the Humics – effects of water colour and interspecific competition on the feeding efficiency of planktivorous perch', Boreal Environment Research, 17, pp. 305–312.

Eur-Lex. (2014). *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy*. [online]
Available at: https://eur-lex.europa.eu/eli/dir/2000/60/oj [Accessed 8 Jan. 2024].

Eur-Lex. (2017). *Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy.* [online]
Available at: https://eur-lex.europa.eu/eli/dir/2008/56/oj [Accessed 8 Jan. 2024].

EC (2003). Planning processes. Guidance document no 11. *Common Implementation Strategy for the Water Framework Directive (2000/60/EC)*. [online]
Available at: < https://circabc.europa.eu/sd/a/4de11d70-5ce1-48f7-994d-65017a862218/Guidance%20No%2011%20-%20Planning%20Process%20(WG%202.9).pdf > [Accessed 8 Jan. 2024].

EC (2020). Marine Environment. [online] Available at: <https://environment.ec.europa.eu/topics/marine-environment_en > [Accessed 8 Jan. 2024].

Fölster, J. *et al.* (2014) 'Swedish monitoring of surface waters: 50 years of adaptive monitoring', Ambio, 43(Suppl 1), pp. 3–18.

Haakana, H. and Huuskonen, H. (2008) 'Effects of intensive fishing on the perch population in a large oligotrophic lake in eastern Finland', *Fisheries research*, 91(2), pp. 144–150.

Hansson, S. *et al.* (2022) 'Habitat modifications from coastal development in a Baltic Sea archipelago – Impact on fish, primarily on eurasian perch (*Perca fluviatilis*)', *Estuarine, coastal and shelf science*, 277, pp. 108036-.

HaV (2020a). *Abborre*. [online] Havochvatten. Available at: < https://www.havochvatten.se/arter-och-livsmiljoer/arter-och-naturtyper/abborre.html > [Accessed 6 Jan. 2024].

HaV (2020b). Faktablad för att bedöma indikator till miljökvalitetsnorm enligt 19 § havsmiljöförordningen. [online] HaV. Available at: https://www.havochvatten.se/download/18.4549140176c766671ab750b/1611317461841/faktablad-c-4-3-st%C3%B8rkelsstruktur-nyckelart-fisk-kustvatten%20procentE2%20procent80%20procent93abborre.pdf [Accessed 12 Apr. 2024].

HaV (2021). *Abborre - Minimimått, Fredningstid och Fångstbegränsningar*. [online] Havs och Vattenmyndigheten. Available at: https://www.havochvatten.se/fiske-ochhandel/regler-och-lagar/arter-regler-for-fiske-och-rapportering/abborre---minimimatt-fredningstid-och-fangstbegransningar.html [Accessed 4 Jan. 2024].

HaV (2023). *Fångststatistik för fritidsfisket*. [online] Havs och vattenmyndigheten . Available at: https://www.havochvatten.se/data-kartor-och-rapporter/data-och-statistik/officiell-statistik/officiell-statistik---fiske/fangststatistik-for-fritidsfisket.html [Accessed 27 Jan. 2024].

Havsmiljoinstitutet (2021). Fisk/fiske. [online] Sveriges vattenmiljö. Available at: https://www.sverigesvattenmiljo.se/sa-mar-vara-vatten/2021/sammanfattningar/0/0/7#atgard [Accessed 28 Jan. 2024].

Heermann, L. *et al.* (2013) 'Explaining recreational angling catch rates of Eurasian perch, *Perca fluviatilis*: the role of natural and fishing-related environmental factors', *Fisheries management and ecology*, 20(2–3), pp. 187–200.

HELCOM (2010). Hazardous substances in the Baltic Sea – An integrated thematic assessment of hazardous substances in the Baltic Sea. Balt. Sea Environ. Proc. No. 120B. [online] Available at: < https://www.helcom.fi/wp-content/uploads/2019/08/BSEP120B.pdf > [Accessed 7 Jan. 2024].

HELCOM (2015) Guidelines for coastal fish - monitoring sampling methods of HELCOM. Available at: < https://helcom.fi/wp-content/uploads/2019/08/Guidelines-for-Coastal-fish-Monitoring-of-HELCOM.pdf > [Accessed: 01 February 2024].

HELCOM (2018) Input of nutrients by the seven biggest rivers in the Baltic Sea region. Baltic Sea Environment Proceedings No. 161 [online] Available at: https://helcom.fi/wp-content/uploads/2019/12/BSEP163.pdf [Accessed 26 Jan. 2024]

HELCOM (2019) Guidelines for coastal fish monitoring - Ocean best practices. Available at: < https://repository.oceanbestpractices.org/bitstream/handle/11329/2032/HELCOM-Guidelines-for-coastal-fish-monitoring-2019.pdf?sequence=1> [Accessed: 01 February 2024]

HELCOM (2023a). Size structure of coastal fish (Coastal fish size). HELCOM core indicator report. Online. [Accessed 16 Jan. 2024], [https://indicators.helcom.fi/wp-content/uploads/2023/04/coastal-fish-size-indicator_Final_April_2023-1.pdf].

HELCOM (2023b): State of the Baltic Sea. Third HELCOM holistic assessment 2016-2021. Baltic Sea Environment Proceedings n°194. [Accessed 16 Jan. 2024], [https://helcom.fi/wp-content/uploads/2023/10/State-of-the-Baltic-Sea-2023.pdf].

van den Heuvel, L. *et al.* (2020) 'Catch reporting in recreational fishing: Swedish anglers' attitudes and preferences, and the effect of social factors', *Fisheries research*, 223, pp. 105444-.

Hixon, M.A. *et al.* (2014) 'BOFFFFs: on the importance of conserving old-growth age structure in fishery populations', ICES journal of marine science, 71(8), pp. 2171–2185.

Holmgren, K. (2014). Challenges in assessing biological recovery from acidification in Swedish lakes. Ambio 43, 19-29.

Holmgren, K. (2016) Monitoring and ecological status assessment of inland fish assemblages. Deliverable 4.5-1, WATERS Report no. 2016:6. Havsmiljöinstitutet, Sweden

Holmgren, K. *et al*. (2016) 'Long term trends of fish after liming of Swedish streams and lakes', *Atmospheric environment* (1994), 146, pp. 245–251.

Holmgren K. and Petersson, E. (2023) 'Are perch (*Perca fluviatilis* L.) getting larger or smaller in Swedish lakes?', *Ecology of freshwater fish*, 32(4), pp. 735–749.

Huss, M. *et al.* (2019) 'Experimental evidence of gradual size-dependent shifts in body size and growth of fish in response to warming', *Global change biology*, 25(7), pp. 2285–2295.

Jacobsen, L. *et al.* (2015) 'Behavioural strategy of large perch *Perca fluviatilis* varies between a mesotrophic and a hypereutrophic lake', Journal of fish biology, 86(3), pp. 1016–1029.

Jenkins, T.M. *et al.* (1999) 'Effects of Population Density on Individual Growth of Brown Trout in Streams', *Ecology (Durham)*, 80(3), pp. 941–956.

Keppeler, FW. *et al*. (2020) 'The relationship between trophic level and body size in fishes depends on functional traits', *Ecological monographs*, 90(4), pp. 1–19.

Kniebusch, M. *et al.* (2019) 'Temperature variability of the Baltic Sea since 1850 and attribution to atmospheric forcing variables', *Journal of geophysical research. Oceans*, 124(6), pp. 4168–4187.

Kokkonen, E. *et al*. (2019) 'Effects of water temperature and pikeperch (*Sander lucioperca*) abundance on the stock–recruitment relationship of Eurasian perch (*Perca fluviatilis*) in the northern Baltic Sea', Hydrobiologia, 841(1), pp. 79–94.

Kvarnäs, H. (2001) 'Morphometry and hydrology of the four large lakes of Sweden', Ambio, 30(8), pp. 467–474.

Länsstyrelsen Östergötland (2023). Fiske. [online] Länsstyrelsen Östergötland. Available at: https://www.lansstyrelsen.se/ostergotland/djur/fiske.html [Accessed 27 Feb. 2024].

Larson, M. (2012) 'Sweden's Great Lakes', in L. Bengtsson, R.W. Herschy, and R.W. Fairbridge (eds) Encyclopedia of Lakes and Reservoirs. Dordrecht: Springer Netherlands, pp. 761–764. Available at: https://doi.org/10.1007/978-1-4020-4410-6_269.

Lindegarth, M. (2016) *Ecological assessment of Swedish water bodies : development, harmonisation and integration of biological indicators*, *Ecological assessment of Swedish water bodies : development, harmonisation and integration of biological indicators*. Göteborg: Swedish Institute for the Marine Environment (Waters report ; 2016:10).

Lindmark, M. *et al* (2023) 'Larger but younger fish when growth outpaces mortality in heated ecosystem', *eLife*, 12, e82996.

Ljunggren, L. *et al.* (2010) 'Recruitment failure of coastal predatory fish in the Baltic Sea coincident with an offshore ecosystem regime shift', *ICES Journal of Marine Science*, 67(8), pp. 1587–1595. Available at: https://doi.org/10.1093/icesjms/fsq109.

Lozys, L. (2004) ‘The growth of pikeperch (*Sander lucioperca* L.) and perch (*Perca fluviatilis* L.) under different water temperature and salinity conditions in the Curonian Lagoon and Lithuanian coastal waters of the Baltic Sea’, *Hydrobiology*, 514, pp. 105–113. Available at: https://doi.org/10.1023/B:hydr.0000018211.26378.b9.

Marine Finland (2023). 'The Perch Is the National Fish of Finland'. [online] Marine Finland. Available at: https://www.marinefinland.fi/en-US [Accessed 6 Jan. 2024].

Markensten, H. *et al.* (2010) ‘Simulated lake phytoplankton composition shifts toward cyanobacteria dominance in a future warmer climate’, *Ecological applications*, 20(3), pp. 752–767.

Moldan, F. *et al.* (2013) ‘Modeling Past and Future Acidification of Swedish Lakes’, *Ambio*, 42(5), pp. 577–586.

Mitchell, J.D. *et al.* (2019) ‘Shark depredation and behavioural interactions with fishing gear in a recreational fishery in Western Australia’, *Marine ecology. Progress series (Halstenbek)*, 616, pp. 107–122.

Mustamäki, N. *et al.* (2020) ‘Fjällbacka, Västerhavet, 1989–2019; Torhamn, södra Egentliga Östersjön, 2002–2019; Kvädöfjärden, Egentliga Östersjön, 1981–2019; Holmöarna, Bottniska viken, 1989–2019’, Faktablad från integrerad kustfiskövervakning. Sveriges lantbruksuniversitet.

Neumann, R and Micheal, S. Allen (2007) ‘Size Structure’. In Analysis and interpretation of freshwater fisheries data. American Fisheries Society, pp. 375–421

Nilsson, J. *et al.* (2004) ‘Recruitment failure and decreasing catches of Perch (*Perca fluviatilis* L.) and pike (*Esox Lucius* L.) in the coastal waters of southeast Sweden’, *Boreal Env. Res.*, 9.

Olin, M. *et al.* (2012) ‘Importance of maternal size on the reproductive success of perch, *Perca fluviatilis*, in small forest lakes: implications for fisheries management’, *Fisheries management and ecology*, 19(5), pp. 363–374.

Olsson, J. *et al.* (2011) ‘Genetic population structure of perch *Perca fluviatilis* along the Swedish coast of the Baltic Sea’, *Journal of fish biology,* 79(1), pp. 122–137.

Olsson, J. *et al* (2012) ‘Abiotic drivers of coastal fish community change during four decades in the Baltic Sea’, *ICES journal of marine science*, 69(6), pp. 961–970.

Olsson, J. *et al.* (2015) Using catch statistics from the small scale coastal Baltic fishery for status assessment of coastal fish. *Aqua reports 2015:13.* Sveriges lantbruksuniversitet, Öregrund.

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(1), 7.

Östman, Ö. *et al.* (2012) ‘Do cormorant colonies affect local fish communities in the Baltic Sea?’, Canadian journal of fisheries and aquatic sciences, 69(6), pp. 1047–1055.

Östman, Ö. *et al.* (2023) ‘Size-based indicators for assessments of ecological status of coastal fish communities’, *ICES journal of marine science*, 80, pp. 2478-2489.

van Overzee, H.M.J. and Rijnsdorp, A.D. (2015) ‘Effects of fishing during the spawning period: implications for sustainable management’, *Reviews in fish biology and fisheries*, 25(1), pp. 65–83.

Pauly, D. *et al.* (1998) ‘Fishing Down Marine Food Webs’, *Science (American Association for the Advancement of Science)*, 279(5352), pp. 860–863.

Persson, L. *et al.* (2003) ‘Gigantic Cannibals Driving a Whole-Lake Trophic Cascade’, *Proceedings of the National Academy of Sciences - PNAS*, 100(7), pp. 4035–4039.

Pihlajamäki, M. *et al.* (2013) *Deliverable 7.3 Marine Strategies for the Baltic Sea: First steps in the implementation of MSFD in Denmark, Poland, Finland and Sweden*, *Know Seas - Knowledge-based Sustainable Management of Europe's Seas*.

Pope, J.G. *et al.* (1994) ‘Successful Surf-Riding on Size Spectra: The Secret of Survival in the Sea [and Discussion]’, *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences*, 343(1303), pp. 41–49.

Probst, W.N., *et al.* (2012) ‘Using cross-correlations to assess the relationship between time-lagged pressure and state indicators: an exemplary analysis of North Sea fish population indicators’, *ICES journal of marine science*, 69(4), pp. 670–681.

Puharinen, S.-T. (2023) ‘Achieving good marine environmental status in the EU – Implications of the marine strategy framework directive for member states and blue economic activities’, *Marine policy*, 155, pp. 105712-.

Queirós, A.M. *et al.* (2018) ‘Climate change alters fish community size-structure, requiring adaptive policy targets’, *Fish and fisheries (Oxford, England)*, 19(4), pp. 613–621.

Radke, R. J., & Gaupisch, A. (2005). 'Effects of phytoplankton-induced turbidity on predation success of piscivorous Eurasian perch (*Perca fluviatilis*): Possible implications for fish community structure in lakes', *Die Naturwissenschaften*, 92(2), pp. 91–94.

Ritterbusch, D. *et al.* (2022) ‘European fish-based assessment reveals high diversity of systems for determining ecological status of lakes’, *The Science of the total environment*, 802, pp. 149620–149620.

Rehrl, A.-L. *et al.* (2020) ‘Spatial and seasonal trends of organic micropollutants in Sweden’s most important drinking water reservoir’, *Chemosphere (Oxford)*, 249, pp. 126168–126168.

Sass, G.G. and Shaw, S.L. (2020) ‘Catch-and-Release Influences on Inland Recreational Fisheries’, Reviews in fisheries science & aquaculture, 28(2), pp. 211–227.

Sheldon, R.W. *et al.* (1977) ‘Structure of Pelagic Food Chain and Relationship Between Plankton and Fish Production’, *Journal of the Fisheries Research Board of Canada*, 34(12), pp. 2344–2353. Available at: https://doi.org/10.1139/f77-314.

Sheridan, J.A. and Bickford, D. (2011) ‘Shrinking body size as an ecological response to climate change’, *Nature climate change*, 1(8), pp. 401–406.

Shin, Y.-J. *et al.* (2005) ‘Using size-based indicators to evaluate the ecosystem effects of fishing’, *ICES journal of marine science*, 62(3), pp. 384–396. Available at: https://doi.org/10.1016/j.icesjms.2005.01.004.

SIS (2015) Vattenundersökningar - Provtagning av fisk med översiktsnät, Svenska Institutet för Standarder (SIS). Available at: < https://www.sis.se/produkter/miljo-och-halsoskydd-sakerhet/vattenkvalitet/undersokning-av-vattens-biologiska-egenskaper/ssen147572015/ > [Accessed: 01 February 2024].

SLU (2023a). *Abborre Perca Fluviatilis*. [online] SLU Artdatabanken. Available at: https://artfakta.se/artinformation/taxa/206198/detaljer [Accessed 6 Jan. 2024].

SLU (2023b) *Fiskbarometern - Abborre*, *Abborre*. Available at: https://fiskbarometern.se/rapport/2023/species/Abborre [Accessed: 28 January 2024].

SLU Artdatabanken (2020). Rödlista 2020 - övergripande delar. Uppsala: SLU Artdatabanken.

Snickars, M. *et al.* (2010) ‘Habitat selectivity of substrate-spawning fish: modelling requirements for the Eurasian perch *Perca fluviatilis*’, *Marine ecology. Progress series (Halstenbek)*, 398, pp. 235–243.

Sundblad, G. and Bergström, U. (2014) ‘Shoreline development and degradation of coastal fish reproduction habitats’, Ambio, 43(8), pp. 1020–1028.

Sundelöf, A. *et al.* (2022) Fisk- och skaldjursbestånd i hav och sötvatten 2021: Resursöversikt, Fisk- och skaldjursbestånd i hav och sötvatten 2021.

Tammi, J. *et al.* (2003) ‘Fish Status Survey of Nordic Lakes: Effects of Acidification, Eutrophication and Stocking Activity on Present Fish Species Composition’, *Ambio*, 32(2), pp. 98–105.

Tibblin, P. *et al.* (2011) ‘Effects of salinity on growth and mortality of migratory and resident forms of Eurasian perch in the Baltic Sea: Effects of salinity on perch’, *Ecology of freshwater fish*, 21, pp. 200–206.

Vainikka, A. *et al.* (2012) ‘Composition of the Eurasian perch (*Perca fluviatilis*) catches in ice fishing: Does capture order predict body size?’, *Fisheries research*, 115, pp. 24–30.

Vivienne Halleux (2023). 'Review of the marine strategy framework directive (REFIT)'. [online] Legislative Train Schedule . Available at: < https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/file-review-of-the-marine-strategy-framework-directive> [Accessed 9 Jan. 2024].

VISS (2023). *Östersjön*. [online] Vatteninformationssystem Sverige. Available at: https://viss.lansstyrelsen.se/MarineRegions.aspx?marineRegionEUID=BAL-SE-RG-Ostersjon [Accessed 20 Dec. 2023].

WISE (2018). *Water Framework Directive*. [online] https://water.europa.eu/freshwater. Available at: < https://water.europa.eu/freshwater/europe-freshwater/water-framework-directive > [Accessed 8 Jan. 2024].

Woolway, R.I. *et al.* (2022) ‘Lakes in Hot Water: The Impacts of a Changing Climate on Aquatic Ecosystems’, *Bioscience*, 72(11), pp. 1050–1061.

WWF (2022) 'The Baltic', [online] Available at: < https://www.wwfbaltic.org/about/the-baltic/ .> [Accessed 7 Jan. 2024]

Popular Science Summary

Large individuals in a fish population play a crucial role in reproduction, making them essential to the sustainability of fish populations. Large fish predators, such as *Perca fluviatilis*, due to their wide distribution and role as predators, are a key element of the fish fauna, contributing to the food web and ecosystem functionality. In Sweden, the perch is present in aquatic systems such as coastal areas, large and small lakes. However, little is known about the factors that influence the size of large individuals within its populations. This species is an essential target for both commercial and recreational fishing. Nevertheless, due to Swedish legislation on the nature of public and private ownership of aquatic ecosystems, coordinating recreational fishing monitoring programs poses a challenge to obtain a clear picture of its impact on large perch.

Few studies have examined and compared large perch size's spatial and temporal patterns between aquatic systems. The data used for this study come from SLU Aqua's NORS and KUL databases, which are open to the public and cover the three perch habitats. The main objective of the thesis was to determine the mean size of the largest perch within and between ecosystem types. A size indicator called L90, which is the length of fish at the 90th percentile of the size distribution in a population, was used to identify possible spatial gradients based on the size of large perch in the systems studied. In other words, within a group, L90 corresponds to the length of the smallest individual among the 10% largest. For each ecosystem, data were selected from gillnet observations, with a minimum selected perch size of 15 cm.

The study showed a marked increase in L90 over time and a difference between systems. The average size of a Swedish large perch for 2016-2022 was 27.3 cm (respectively, coast areas: 26.1 cm, large lakes: 27.2 cm, and small lakes: 28.7 cm). The proximity of the L90 averages between the systems suggests that, on a large scale, the regional factors affect the sizes of large perch similarly. Next, analyses were performed to determine whether L90 significantly differed from one system to another. The results showed a significant size difference between coastal systems and small lakes, suggesting better conditions for big perch in a lake environment.

Then, L90 means were observed according to the geographical coordinates of the monitoring areas. Graphical representations revealed the systems' absence of significant N-S and E-W spatial gradients. However, notable local differences in mean L90 were observed in several geographically close monitoring areas. It suggests that small-scale factors have a more substantial influence on perch L90 than regional factors.

The variations in mean L90, at a local level, suggested the existence of small-scale growth patterns, unique habitat characteristics, differences in the level of human impact, and geographical isolation. Thus, in-depth studies in specific sections containing local populations with distinct mean L90s despite geographical proximity are required to understand how environmental, genetic, and anthropogenic factors influence the L90 of the large perch.

Although the L90 indicator is suitable for fish populations in coastal areas and applicable to large lakes, its practical use requires adjustments adapted to the aquatic system. Further studies would be needed to determine whether the threshold value of L90 for large lakes should be identical to that for coastal areas. Also, this study is the first L90 analysis of perch small lakes since large fish are not involved in assessing the good status of this ecosystem. As the number of fish caught in many lakes was below the data inclusion threshold, only a small subset of all perch lakes was included in the analysis. Of the 2,000 perch lakes sampled in the SLU database, only a maximum of 86 small lakes were included, representing less than 5%.

In summary, this study marks the first comparative study in Sweden of three distinct aquatic perch systems using the L90 size metric. Despite variations in the environments studied requiring adjustments in the data, the L90 appears to be a versatile indicator applicable to all three aquatic ecosystems. The results underline the feasibility and the need to study perch populations at regional and local scales within and between systems.

Acknowledgements

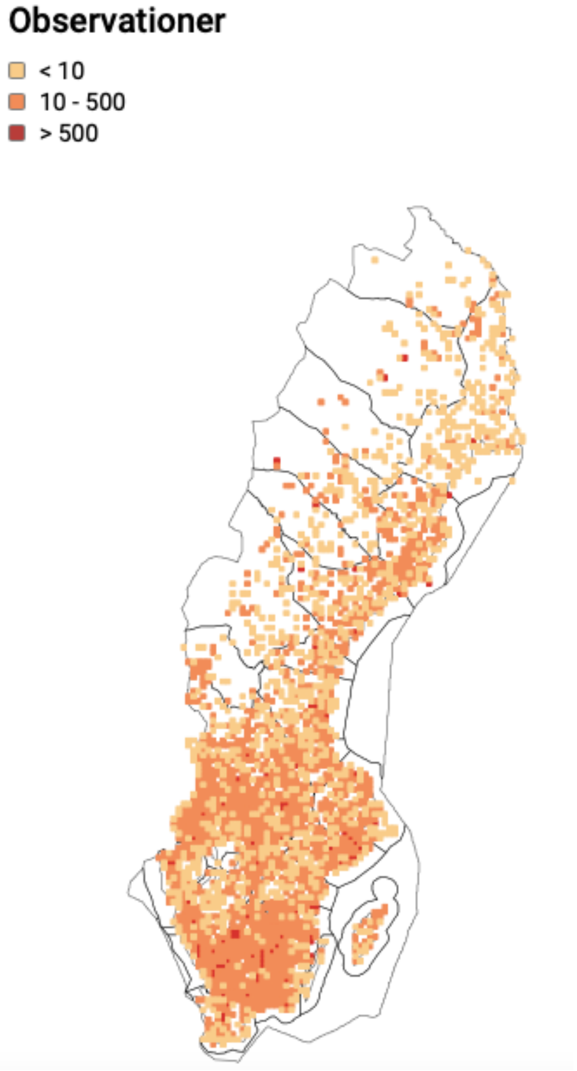
I would like to express my deep gratitude to my thesis supervisor, Jens Olsson, from the SLU-Aqua, for his invaluable guidance and support throughout my thesis. His exemplary professionalism, unwavering encouragement, and strong moral compass have shaped this study. I am also profoundly grateful to my co-supervisor, Kerstin Holmgren from SLU-Aqua, for her patience, insightful vision, and unwavering dedication to my thesis. Her expertise and guidance were indispensable in navigating the complexities of my research. I am immensely grateful for their collaborative spirit and for awakening my interest for the world of *Perca fluviatilis*, which turned out to be far more important and multifaceted than I had ever imagined.

In addition, I appreciate the invaluable contributions of Elisabeth Bolund, Martin Ogonowski, and Göran Sundblad from the SLU-Aqua, who provided all the data used in this thesis.

I would also like to thank my parents and my twin sister, whose unfailing love, encouragement, and support have been a constant source of strength throughout my studies. And, of course, thank you to my friends: Fabien, thank you for your help and for listening to me when I felt alone in front of my computer, working on my R's. Morgane, thank you for motivating me not to forget why I started this Master thesis. Tristan, thank you for making me laugh like nobody else, even when I am talking about the perch.

Appendix 1

The map shows the number of perch sightings in Sweden's inland lakes. These sightings come from several different sources collected by SLU.

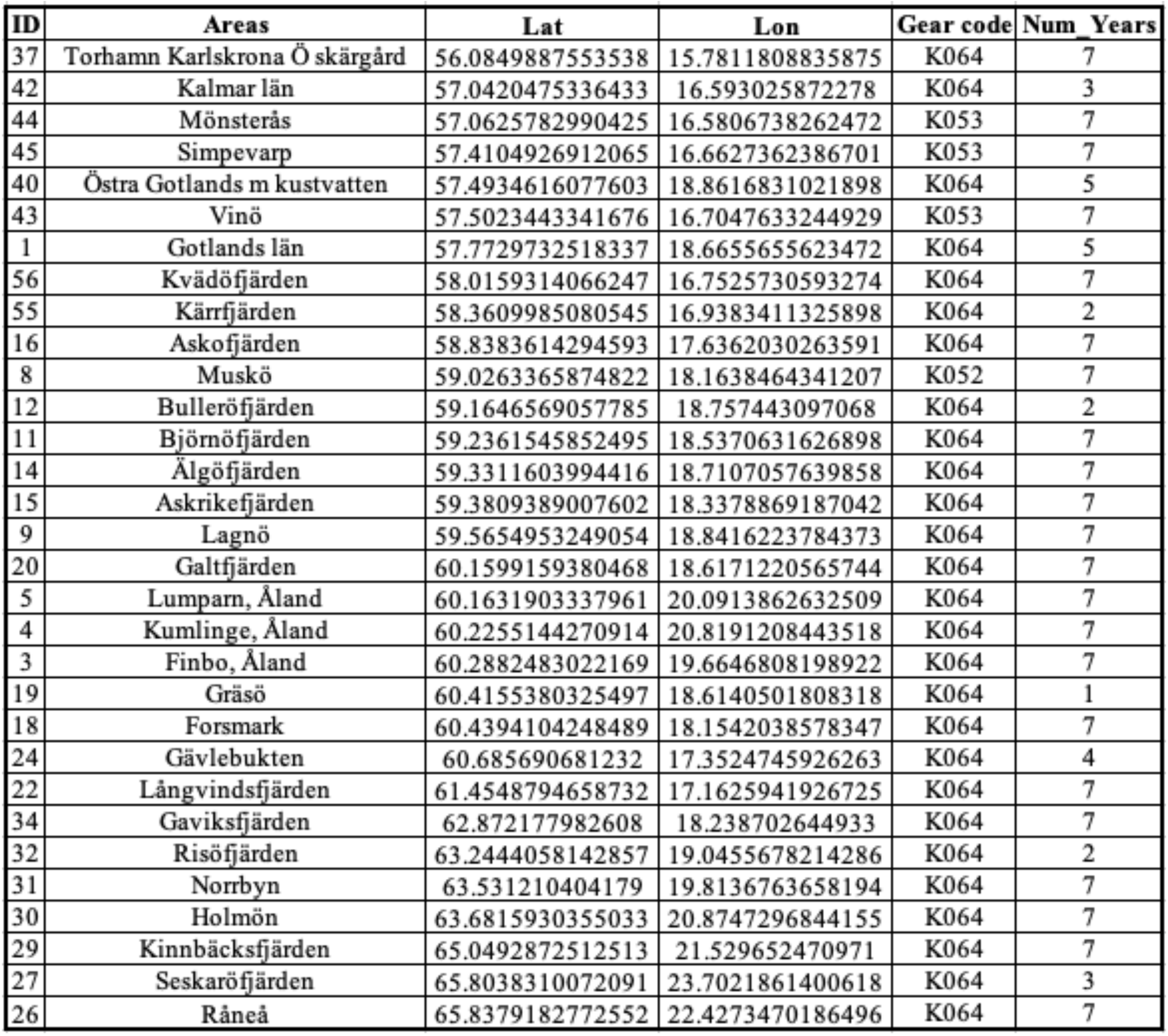


Appendix 1. Map of *Perca fluviatilis* observations in Swedish inland waters (consulted March 20, 2024, *https://artfakta.se/artinformation/taxa/206198/detaljer)*

Appendix 2

The table below lists the areas sampled (ID and name) in the Baltic Sea by geographic coordinates (latitude and longitude), the type of gear used for data collection, and the number of sampling years.

Appendix 2. 2016-2022 Baltic Sea coastal sampled areas



ID	Areas	Lat	Lon	Gear code	Num_Years
37	Torhamn Karlskrona Ö skärgård	56.0849887553538	15.7811808835875	K064	7
42	Kalmar län	57.0420475336433	16.593025872278	K064	3
44	Mönsterås	57.0625782990425	16.5806738262472	K053	7
45	Simpevarp	57.4104926912065	16.6627362386701	K053	7
40	Östra Gotlands m kustvatten	57.4934616077603	18.8616831021898	K064	5
43	Vinö	57.5023443341676	16.7047633244929	K053	7
1	Gotlands län	57.7729732518337	18.6655655623472	K064	5
56	Kvädöfjärden	58.0159314066247	16.7525730593274	K064	7
55	Kärrfjärden	58.3609985080545	16.9383411325898	K064	2
16	Askofjärden	58.8383614294593	17.6362030263591	K064	7
8	Muskö	59.0263365874822	18.1638464341207	K052	7
12	Bulleröfjärden	59.1646569057785	18.757443097068	K064	2
11	Björnöfjärden	59.2361545852495	18.5370631626898	K064	7
14	Älgöfjärden	59.3311603994416	18.7107057639858	K064	7
15	Askrikefjärden	59.3809389007602	18.3378869187042	K064	7
9	Lagnö	59.5654953249054	18.8416223784373	K064	7
20	Galtfjärden	60.1599159380468	18.6171220565744	K064	7
5	Lumparn, Åland	60.1631903337961	20.0913862632509	K064	7
4	Kumlinge, Åland	60.2255144270914	20.8191208443518	K064	7
3	Finbo, Åland	60.2882483022169	19.6646808198922	K064	7
19	Gräsö	60.4155380325497	18.6140501808318	K064	1
18	Forsmark	60.4394104248489	18.1542038578347	K064	7
24	Gävlebukten	60.685690681232	17.3524745926263	K064	4
22	Långvindsfjärden	61.4548794658732	17.1625941926725	K064	7
34	Gaviksfjärden	62.872177982608	18.238702644933	K064	7
32	Risöfjärden	63.2444058142857	19.0455678214286	K064	2
31	Norrbyn	63.531210404179	19.8136763658194	K064	7
30	Holmön	63.6815930355033	20.8747296844155	K064	7
29	Kinnbäcksfjärden	65.0492872512513	21.529652470971	K064	7
27	Seskaröfjärden	65.8038310072091	23.7021861400618	K064	3
26	Råneå	65.8379182772552	22.4273470186496	K064	7

Appendix 3

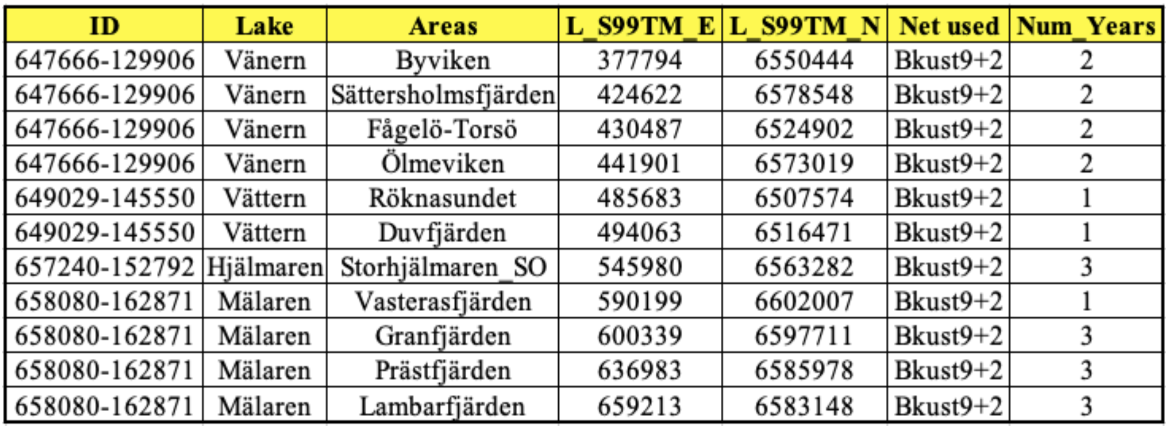
Appendix 3. T-Welch's test of mean L90 and mean Ntot of sampled areas in the Baltic Sea

Mean L90					
	Mean	**T-value**	**Df**	**p-value**	**95%**
1987-2015	25.649				
2016-2022	26.114				
Result		-0.683	55	0.497	[-1.828, 0.898]
Mean Ntot					
	Mean	**T-value**	**Df**	**p-value**	**95%**
1987-2015	373.271				
2016-2022	380.158				
Result		-0.121	55	0.90	[-121.312, 107.546]

Appendix 4

The table below lists the areas sampled (ID and name) in the large lakes by geographic coordinates (SWEREF99 Easting and Northing), the type of net used for data collection, and the number of sampling years.

Appendix 4. 2016-2022 Large Lake areas



ID	Lake	Areas	L_S99TM_E	L_S99TM_N	Net used	Num_Years
647666-129906	Vänern	Byviken	377794	6550444	Bkust9+2	2
647666-129906	Vänern	Sättersholmsfjärden	424622	6578548	Bkust9+2	2
647666-129906	Vänern	Fågelö-Torsö	430487	6524902	Bkust9+2	2
647666-129906	Vänern	Ölmeviken	441901	6573019	Bkust9+2	2
649029-145550	Vättern	Röknasundet	485683	6507574	Bkust9+2	1
649029-145550	Vättern	Duvfjärden	494063	6516471	Bkust9+2	1
657240-152792	Hjälmaren	Storhjälmaren_SO	545980	6563282	Bkust9+2	3
658080-162871	Mälaren	Vasterasfjärden	590199	6602007	Bkust9+2	1
658080-162871	Mälaren	Granfjärden	600339	6597711	Bkust9+2	3
658080-162871	Mälaren	Prästfjärden	636983	6585978	Bkust9+2	3
658080-162871	Mälaren	Lambarfjärden	659213	6583148	Bkust9+2	3

Appendix 5

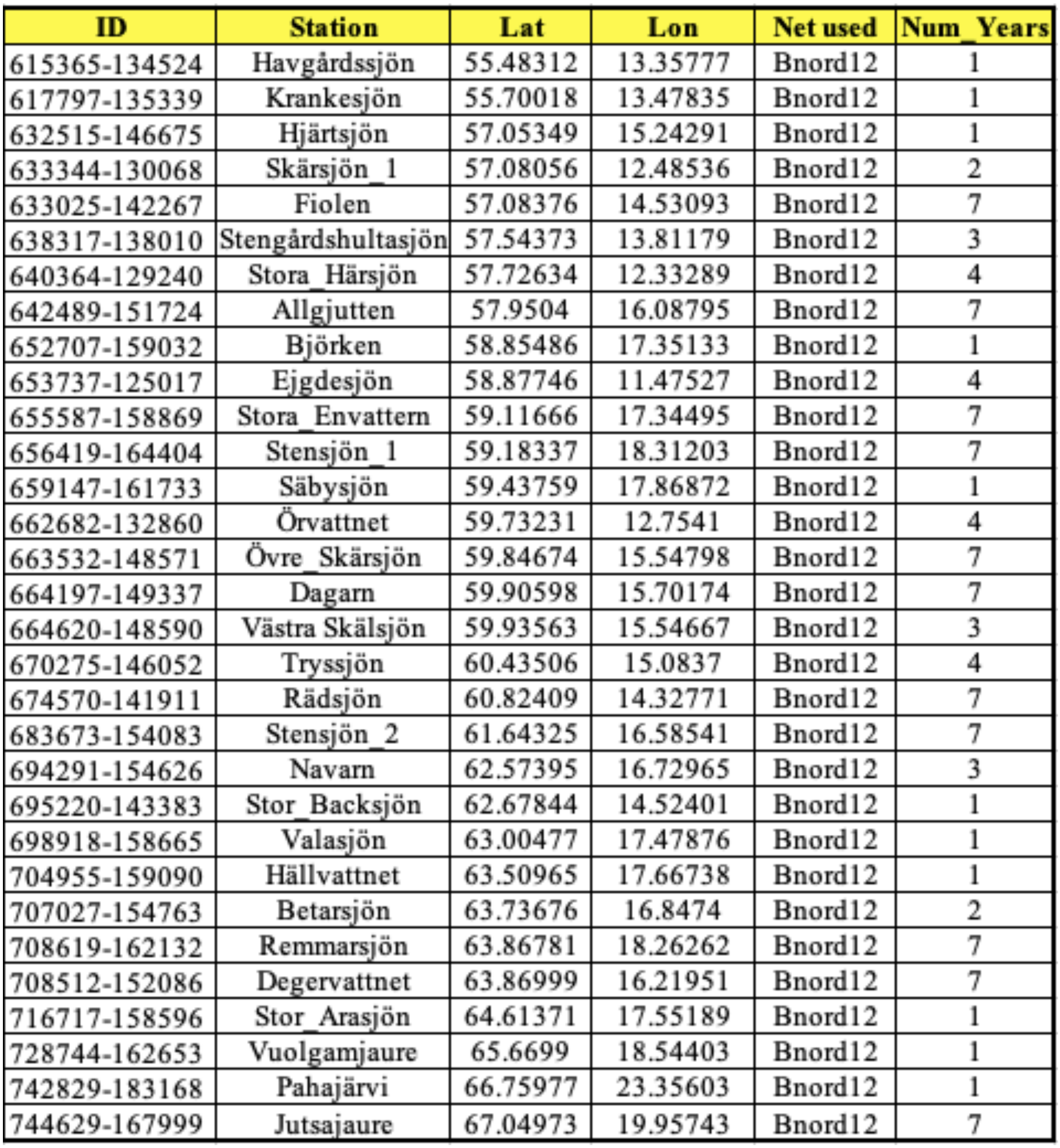
Appendix 5. T-Welch's test of mean L90 and mean Ntot of sampled areas in the large lakes

Mean L90					
	Mean	**T-value**	**Df**	**p-value**	**95%**
2008-2015	25.476				
2016-2022	27.189				
Result		-2.170	26	0.039	[-3.330, -0.0898]
Mean Ntot					
	Mean	**T-value**	**Df**	**p-value**	**95%**
2008-2015	237.863				
2016-2022	313.256				
Result		-0.834	13	0.42	[-270.05, 119.265]

Appendix 6

The table below lists the small lakes sampled (ID and name) by geographic coordinates (Latitude and Longitude), the type of net used for data collection, and the number of sampling years.

Appendix 6. 2016-2022 Small lakes sampled



ID	Station	Lat	Lon	Net used	Num_Years
615365-134524	Havgårdssjön	55.48312	13.35777	Bnord12	1
617797-135339	Krankesjön	55.70018	13.47835	Bnord12	1
632515-146675	Hjärtsjön	57.05349	15.24291	Bnord12	1
633344-130068	Skärsjön_1	57.08056	12.48536	Bnord12	2
633025-142267	Fiolen	57.08376	14.53093	Bnord12	7
638317-138010	Stengårdshultasjön	57.54373	13.81179	Bnord12	3
640364-129240	Stora_Härsjön	57.72634	12.33289	Bnord12	4
642489-151724	Allgjutten	57.9504	16.08795	Bnord12	7
652707-159032	Björken	58.85486	17.35133	Bnord12	1
653737-125017	Ejgdesjön	58.87746	11.47527	Bnord12	4
655587-158869	Stora_Envattern	59.11666	17.34495	Bnord12	7
656419-164404	Stensjön_1	59.18337	18.31203	Bnord12	7
659147-161733	Säbysjön	59.43759	17.86872	Bnord12	1
662682-132860	Örvattnet	59.73231	12.7541	Bnord12	4
663532-148571	Övre_Skärsjön	59.84674	15.54798	Bnord12	7
664197-149337	Dagarn	59.90598	15.70174	Bnord12	7
664620-148590	Västra Skälsjön	59.93563	15.54667	Bnord12	3
670275-146052	Tryssjön	60.43506	15.0837	Bnord12	4
674570-141911	Rädsjön	60.82409	14.32771	Bnord12	7
683673-154083	Stensjön_2	61.64325	16.58541	Bnord12	7
694291-154626	Navarn	62.57395	16.72965	Bnord12	3
695220-143383	Stor_Backsjön	62.67844	14.52401	Bnord12	1
698918-158665	Valasjön	63.00477	17.47876	Bnord12	1
704955-159090	Hällvattnet	63.50965	17.66738	Bnord12	1
707027-154763	Betarsjön	63.73676	16.8474	Bnord12	2
708619-162132	Remmarsjön	63.86781	18.26262	Bnord12	7
708512-152086	Degervattnet	63.86999	16.21951	Bnord12	7
716717-158596	Stor_Arasjön	64.61371	17.55189	Bnord12	1
728744-162653	Vuolgamjaure	65.6699	18.54403	Bnord12	1
742829-183168	Pahajärvi	66.75977	23.35603	Bnord12	1
744629-167999	Jutsajaure	67.04973	19.95743	Bnord12	7

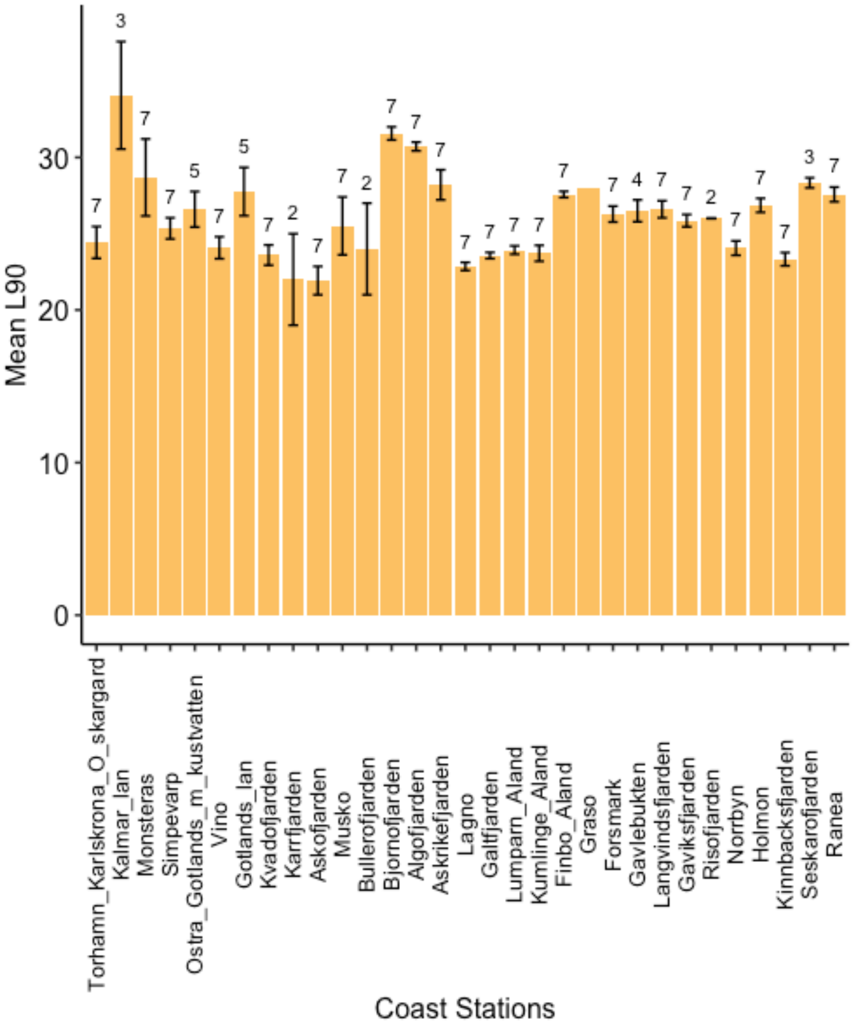
Appendix 7

Appendix 7: T-Welch's test of mean L90 and mean Ntot of sampled areas in the small lakes

Mean L90					
	Mean	**T-value**	**Df**	**p-value**	**95%**
1994-2015	26.138				
2016-2022	28.651				
Result		-2.625	49	0.012	[-4.437, -0.590]

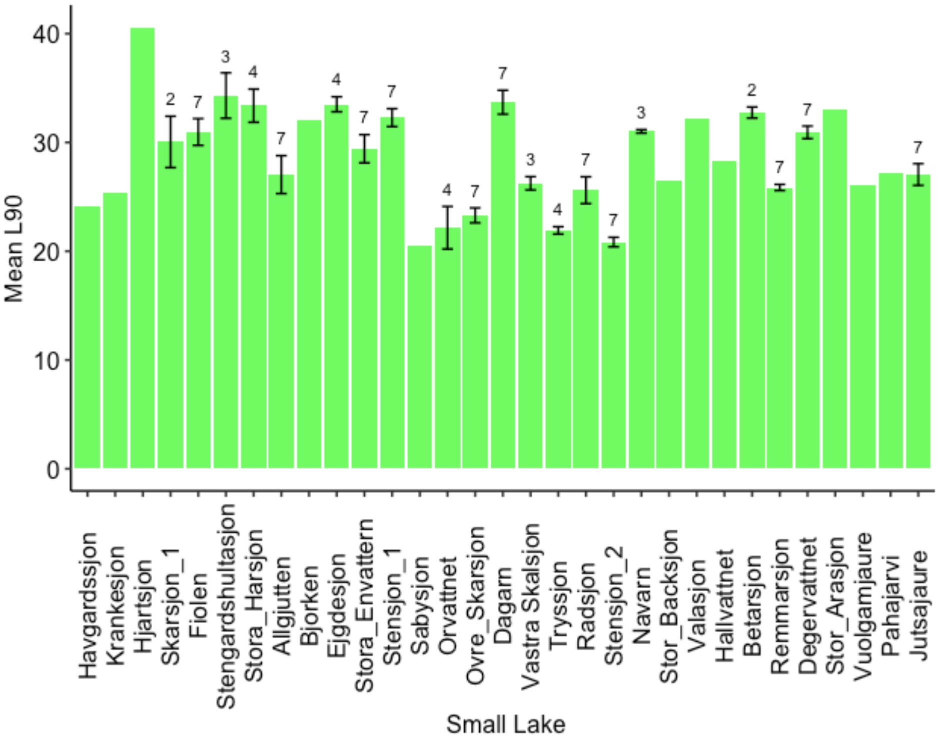
Mean Ntot					
	Mean	**T-value**	**Df**	**p-value**	**95%**
1994-2015	165.489				
2016-2022	176.806				
Result		-0.528	50	0.60	[-54.378, 31.742]

Appendix 8



Appendix 8. Mean L90 of Baltic Sea coastal areas sampled in 2016-2022. The standard error and the number of collection years are shown for each area, except for those with only one collection year. Areas are ordered according to their latitude coordinates along a south-north gradient (Appendix 2)

Appendix 9



Appendix 9. Vertical bar chart of the mean number of L90 according to the small lakes sampled in 2016-2022. The standard error and the number of collection years are shown for each station, except for those with only one collection year. Stations are ordered according to their latitude coordinates along an south-north gradient (Appendix 6).

Appendix 10

The category represents the three systems in the study: coastal areas, large lakes, small lakes.

Appendix 10. Comparison between system - ANCOVA

ANCOVA					
	Df	**Sum Sq**	**Mean Sq**	**F value**	**Pr(>F)**
Category	2	100.2	50.08	3.86	0.026
Num_Years	1	18.4	18.37	1.416	0.24
Residuals	69	895.1	12.97		

Annex

R script - Question 1

Descriptive statistics

```
library(readxl)
data=read_xlsx("[PathToFile]/NameoftheExcel.xlsx")
data <- data[data$Ar >= 2016 & data$Ar <= 2022, ]
Table <- aggregate(L90 ~ Lokal, data=data, FUN=mean)
Table$Median <- tapply(data$L90, data$Lokal, FUN=median)
Table$Variance <- tapply(data$L90, data$Lokal, FUN=var)
Table$Deviation <- tapply(data$L90, data$Lokal, FUN=sd)
Table$Mean_Ntot <- tapply(data$Ntot, data$Lokal, FUN=mean)
Table$Num_Years <- tapply(data$Ar,data$Lokal,
                   function(x) length(unique(x)))
names(Table)[1] <- "Lokal"
names(Table)[2] <- "Mean"
names(Table)[3] <- "Median"
names(Table)[4] <- "Variance"
names(Table)[5] <- "Standard_Deviation"
names(Table)[6] <- "Mean_Ntot"
names(Table)[7] <- "Num_Years"
Table <- as.data.frame(Table)
Table_final <- Table[(Table$Mean_Ntot > 100 & Table$Num_Years <= 2) |
                 (Table$Mean_Ntot > 50 & Table$Num_Years >= 3), ]
```

T-Welch test

```
library(readxl)
data <- read_xlsx("[PathToFile]/NameoftheExcel.xlsx")
welch_test <- t.test(Mean_L90 ~ Period, data = data, var.equal = FALSE)
print(welch_test)
```

Figure 4d: L90 in Mälaren Lake

```
library(ggpubr)
library(ggplot2)
library(readxl)
data=read_xlsx("[PathToFile]/NameoftheExcel.xlsx")
data_L <- subset(data, Lake == "Malaren")
head(data_L)
ggplot(data_L, aes(x = Ar, y = Size, fill = Area)) +
  geom_point(size = 4, shape = 24, color="black") +
  stat_summary(fun = mean, geom = "line", aes(group = 1), color = "black") +
  labs(x = "Year", y = "L90", title = " Lake Mälaren") +
  theme_pubr() +
  theme(plot.title = element_text(size = 11, color= "black", hjust = 0.5),
        legend.text = element_text(size = 11),
        legend.title = element_text(size = 11)) +
  scale_fill_discrete(name = "Area")
```

R script - Question 2

Shapiro-Wilk

```
library(readxl)
data <- read_xlsx("[PathToFile]/NameoftheExcel.xlsx")
shapiro.test(data$Mean_L90)
```

Mean L90 Histogram

```
library(readxl)
data <- read_xlsx("[PathToFile]/NameoftheExcel.xlsx")
hist(data$Mean_L90, freq = FALSE, main = "Mean L90 Histogram", xlab="Mean L90", ylab="Density")
M <- mean(data$Mean_L90)
SD <- sd(data$Mean_L90)
x <- seq(min(data$Mean_L90), max(data$Mean_L90), length.out = 100)
y <- dnorm(x, mean = M, sd = SD)
lines(x, y, col = "red")
```

Statistical power calculation for an ANCOVA

```
install.packages("pwr")
library(pwr)
effect_size <- 0.5
SD <- 4
n_groups <- 3
n_total <- 73
n_covariate <- 1
power <- pwr.anova.test(k = n_groups, n = n_total, f = effect_size, sig.level = 0.05)
power$power
```

ANCOVA (Appendix 10)

```
library(readxl)
data <- read_xlsx("[PathToFile]/NameoftheExcel.xlsx")
model_ancova <- aov(Mean_L90 ~ Category + Num_Years, data = data)
summary(model_ancova)
```

Bonferroni Pairwise comparison (Table 9)

```
library(readxl)
data <- read_xlsx("[PathToFile]/NameoftheExcel.xlsx")
result_bonferroni <- pairwise.t.test(data$Mean_L90, data$Category,
p.adjust.method = "bonferroni")
print(result_bonferroni)
```

R script - Question 3

Figure 6

```
library(ggplot2)
library(ggpubr)
library(readxl)
data <- read_xlsx("[PathToFile]/NameoftheExcel.xlsx")
head(data)
ggplot(data, aes(x = Lon, y = Lat, size = Mean, color = Mean)) +
  geom_point() +
  scale_x_continuous(expand = c(1,5), breaks = seq(min(15), max(25), by =5)) +
  scale_size_continuous(range = c(2, 10)) +
  scale_color_gradient(low = "#40E0D0", high ="#000033")+
  labs(title = "L90 averages by coastal station along East-West gradient 2016-
2022",
       x = "Longitude", y = "Latitude",
       size = "Mean L90", color = "Mean L90") +
  theme_pubr() +
  theme(plot.title = element_text(hjust = 0.5))
```

Figure 7

```
library(ggplot2)
library(ggpubr)
library(readxl)
data=read_xlsx("[PathToFile]/NameoftheExcel.xlsx")
data$Mean_L90 <- as.numeric(data$Mean_L90)
data$Standard_Error <- as.numeric(data$Standard_Error)
data$Lake <- factor(data$Lake, levels = unique(data$Lake), ordered = TRUE)
ggplot(data, aes(x = Lake, y = Mean_L90)) +
  geom_bar(stat = "identity", fill = "blue", alpha = 0.7) +
  geom_errorbar(aes(ymin = Mean_L90 - Standard_Error, ymax = Mean_L90 +
Standard_Error),
```

```
              width = 0.4, position = position_dodge(0.9)) +
  geom_text(aes(label = Num_Years, y = Mean_L90 + Standard_Error + 0.5),
          vjust = -0.5, size = 3, position = position_dodge(width = 0.9))+
  labs(title = "Mean L90 with Standard Error for Large Lakes - Collection Years
2016-2022",
      x = " Large Lake sampling areas", y = "Mean L90") +
  theme_pubr() +
  theme(axis.text.x = element_text( size = 9.5, color = "black", angle = 90, vjust =
0.5, hjust =0.5),
       axis.text.y = element_text( color = "black"),
       plot.title = element_text( size = 9.5, color="black", hjust = 0.5))
```

Publishing and archiving

Approved students' theses at SLU are published electronically. As a student, you have the copyright to your own work and need to approve the electronic publishing. If you check the box for **YES**, the full text (pdf file) and metadata will be visible and searchable online. If you check the box for **NO**, only the metadata and the abstract will be visible and searchable online. Nevertheless, when the document is uploaded it will still be archived as a digital file. If you are more than one author, the checked box will be applied to all authors. You will find a link to SLU's publishing agreement here:

- https://libanswers.slu.se/en/faq/228318.

☒ YES, I/we hereby give permission to publish the present thesis in accordance with the SLU agreement regarding the transfer of the right to publish a work.

☐ NO, I/we do not give permission to publish the present work. The work will still be archived and its metadata and abstract will be visible and searchable.