MONITORING AND ECOLOGICAL STATUS ASSESSMENT OF FISH ASSEMBLAGES IN INLAND WATERS

Kerstin Holmgren

WATERS Report no. 2016:6

Deliverable 4.5-1

MONITORING AND ECOLOGICAL STATUS ASSESSMENT OF FISH ASSEMBLAGES IN INLAND WATERS

Kerstin Holmgren, Swedish University of Agricultural Sciences, Department of Aquatic Resources, Institute of Freshwater Research

WATERS partners:

GÖTEBORGS UNIVERSITET

Stockholms universitet

UMEÅ UNIVERSITET

AARHUS UNIVERSITY

SVERIGES VATTENEKOLOGER

Marine Monitoring RESEARCH & CONSULTING

SLU

SMHI

TOXICON AB

Hafok AB

AquaBiota WATER RESEARCH

WATERS: Waterbody Assessment Tools for Ecological Reference conditions and status in Sweden

WATERS Report no. 2016:6. Deliverable 4.5-1
Title: Monitoring and ecological status assessment of inland fish assemblages
Cover photo: Kerstin Holmgren
Publisher: Havsmiljöinstitutet/Swedish Institute for the Marine Environment,
P.O. Box 260, SE-405 30 Göteborg, Sweden
Published: June 2016
ISBN 978-91-983101-7-7

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

http://www.waters.gu.se/rapporter

WATERS is a five-year research programme that started in spring 2011. The programme's objective is to develop and improve the assessment criteria used to classify the status of Swedish coastal and inland waters in accordance with the EC Water Framework Directive (WFD). WATERS research focuses on the biological quality elements used in WFD water quality assessments: i.e. macrophytes, benthic invertebrates, phytoplankton and fish; in streams, benthic diatoms are also considered. The research programme will also refine the criteria used for integrated assessments of ecological water status.

This report is a deliverable of one of the scientific sub-projects of WATERS focusing on fish in inland waters. It presents a review of inland fish monitoring, indicators of ecological status, and relates the current Swedish assessment methods to those used in other countries. Attention is paid to applicability depending on sampling methods and the variation of size and other characteristics of Swedish inland waters.

WATERS is funded by the Swedish Environmental Protection Agency and coordinated by the Swedish Institute for the Marine Environment. WATERS stands for 'Waterbody Assessment Tools for Ecological Reference Conditions and Status in Sweden'. Programme details can be found at: http://www.waters.gu.se

Table of Contents

Summary

Inland waters cover many different habitats within small to very large river basins. Local lake or stream fish assemblages often comprise just a few of the fish species pool within a certain river basin. Inland fish was part of Swedish environmental monitoring long before implementation of the WFD. Sampling methods used in smaller lakes and streams became European standard methods, i.e. sampling with multi-mesh gillnets in lakes and electrofishing by wading in streams. Monitoring data from small lakes and streams were previously used for developing multi-metric fish indices EQR8 for lakes and VIX for streams. Swedish fish data were also used in European collaboration projects, to develop European fish indices as well as for study of more basic relationships with natural environmental variability and anthropogenic pressures. The same sampling and assessment methods cannot, however, be used as successfully in larger water bodies.

Recent advances in monitoring confirm the common view that different sampling methods are complementary rather than perfectly related and interchangeable. Gillnet samples from lakes have been compared with e.g. electrofishing of shorelines and hydroacoustics in pelagic areas. In running waters, electrofishing by wading have similarly been compared with boat electrofishing, horizontal hydroacoustics and sampling with a new Norden multi-mesh Stream Survey Net (NSSN). Combinations of sampling gears often result in longer species lists compared to any single method, and abundance and size- or age-based metrics may not easily be compared from one gear to another.

Recent experiences of status assessment of lakes indicate that just a few fish abundance metrics respond clearly to eutrophication at the European scale. Effects of eutrophic conditions on species diversity and size structure were harder to distinguish from geographic and climate-related factors, but may still be useful indicators at more regional scales. Age metrics may be even more useful than size metrics for assessment of acidification and to detect trends in changed climate.

Recent studies on stream and river fish assessment addressed hydrological and morphological pressures. The current index VIX, and its pressure-specific side indices worked reasonably well, but alternative indices had higher precision in detecting sites with certain pressures. The improvements involved identification of new functional groups, i.e. species favored or disfavored by certain pressures at relevant geographical scales, instead of the previously used general classification of fish species as tolerant or intolerant.

Svensk sammanfattning

Inlandsvatten omfattar olika livsmiljöer inom små till mycket stora avrinningsområden. Lokala fisksamhällen har ofta bara ett fåtal av de fiskarter som förekommer i inom ett specifikt avrinningsområde. Fiskar ingick i svensk miljöövervakning långt innan genomförandet av ramdirektivet för vatten. Provfiskemetoder för mindre sjöar och vattendrag blev Europeiska standardmetoder, det vill säga provfiske med Nordiska översiktsnät i sjöar och elfisken i vadbara vattendrag. Övervakningsdata från små sjöar och vattendrag användes för utveckling av de multimetriska fiskindexen EQR8 för sjöar och VIX för vattendrag. Svenska fiskdata användes också i europeiska samarbeten, för utveckling av europeiska fiskindex samt för studier av mer grundläggande relationer med naturliga miljövariabler och mänsklig påverkan. Samma provtagnings och bedömningsmetoder kan dock inte användas på samma sätt i större vattendrag och sjöar.

De senaste framstegen inom övervakning bekräftar den vanliga uppfattningen att olika provtagningsmetoder kompletterar varandra snarare än att vara helt jämförbara och utbytbara. Nätprovfiske i sjöar har jämförts med bl.a. elfiske längs stränder och hydroakustik i pelagiska områden. I vattendrag har vadningselfiske jämförts med båtelfiske, horisontell hydroakustik och provfiske med en ny typ av strömöversiktsnät. Kombinationer av provfiskemetoder resulterar ofta i längre artlistor jämfört med någon enskild metod, och abundans- och storleks- eller åldersbaserade indikatorer ger inte självklart jämförbara värden med olika metoder.

Nya erfarenheter kring statusbedömning i sjöar indikerar att bara ett fåtal abundansindikatorer svarar tydligt på övergödning på europeisk nivå. Effekter av eutrofa förhållanden på artrikedom och storleksstruktur var svårare att skilja från geografiska och klimatrelaterade faktorer, men kan ändå vara användbara indikatorer på en mer regional skala. Åldersbaserade indikatorer kan vara ännu mer användbara än storleksindikatorer för bedömning av försurning och för att upptäcka trender i ett förändrat klimat.

Nyligen genomförda studier om statusbedömning på fisk i rinnande vatten behandlade hydrologisk och morfologisk påverkan. Det nuvarande indexet VIX, och dess sidoindex fungerade ganska bra, men alternativa index hade högre precision för att upptäcka elfiskestationer med en viss typ av hydromorfologisk påverkan. I förbättringen ingick identifiering av nya funktionella grupper, det vill säga arter gynnade eller missgynnade av en specifik påverkan på relevanta geografiska skalor, istället för att som tidigare klassa vissa fiskarter som toleranta eller intoleranta.

1. Introduction

Swedish inland waters range from small tributary streams to moderately large catchments at river mouths, and from small ponds, lakes and reservoirs to among some of the largest lake in Europe (Sonesten 2013, Munawar 2014). Fish occur naturally or have been introduced in all but the smallest and most isolated water bodies (Tammi et al. 2003). The great variety of waterbody types implies different challenges related to fish monitoring and assessment of ecological status, according to the European Water Framework Directive (WFD, European Commission 2000).

Fish assemblages in inland waters include freshwater species that spend most or all of their life cycles in lakes or rivers, as well as diadromous species that migrate between freshwater and estuarine or marine water systems. The natural dispersal of obligate freshwater fish is constrained by oceanic barriers, and inland fish migration occurs in dendritic networks of connected lakes and running waters. Intentional and unintentional human introduction of exotic fish species is considered a great threat to the native fish fauna in many parts of the world (Leprieur et al. 2008). Some North American salmonids have been introduced to Swedish lakes and streams, but except for brook trout (*Salvelinus fontinalis*), they seldom established self-reproducing populations. Compared to exotic species, human stocking of native fish species in Swedish inland waters have resulted in far more successful establishment of new populations (e.g. Filipsson 1994, Schreiber et al. 2003).

Sweden is part of the Northern Baltic Drainages, according to the global map of freshwater ecoregions (Abell et al. 2008). This ecoregion has relatively low fish species richness (map class 42-66 species) and no endemic species, i.e. all fish species in this ecoregion are also found in at least one other ecoregion. Within European ecoregions the fish species richness increases with increasing drainage basin area (Reyjol et al. 2007). Such positive species-surface area relationships also appear for fish in smaller sub-basin rivers and in freshwater lakes (Eadie et al. 1986, Brucet et al. 2013), as well as within littoral or profundal habitats of the largest lakes of the world (Vadeboncoeur et al. 2011).

The local fish assemblage (in a certain lake or stream reach) includes a subset of the regional species pool that has passed a series of a series of filters, acting at different temporal and spatial scales (Tonn 1990). Filters may be either abiotic (e.g. related to climate, hydrology, morphometry, water chemistry) or biotic factors (e.g. competition, predation and other biological interactions), reflecting natural conditions and/or anthropogenic pressures.

Ecological status of lake and river fish fauna should be assessed with respect to species composition, abundance, occurrence of type-specific sensitive species and age structure (European Commission 2000). For each of these aspects, normative definitions of high, good and moderate status are expressed in relation to undisturbed and water type-specific reference conditions, assuming a detailed knowledge of reference conditions over the nationwide ranges of waterbody characteristics.

Current Swedish fish-based methods for assessment of ecological status for lakes and streams (Holmgren et al. 2007, Beier et al. 2007, Havs- och vattenmyndigheten 2013) fulfil some but not all needs of the WFD. Limitations and gaps were identified both before and after the WATERS program started in 2011. This report presents state of the art as guidance for further development of national methods and/or methods to be shared with other European countries.

2. Objectives

This report summarizes recent findings to support revision and/or extension of the current Swedish fish-based assessment methods for lakes and streams, respectively. It reviews methods of inland fish monitoring, indicators of ecological status, and relates Swedish assessment methods to those used in other countries. Attention is paid to applicability depending on sampling methods and the variation of size and other characteristics of Swedish inland waters.

3. Background

Inland fish was part of Swedish environmental monitoring far before implementation of the WFD (European Commission 2000), and sampling methods were to some extent also harmonized with methods used in other Nordic countries (Appelberg et al. 1995). Repeated national surveys of water chemistry (starting in 1972) revealed that acidification mostly affected smaller catchments (Fölster 2014). After some years of experimental liming a large-scale liming program was started in 1982, and expanded to include 7,500 lakes and more than 11,000 km of water courses (Svenson et al. 1995). Since then most inland environmental monitoring, including fish, targeted limed and non-limed reference sites, in relative small water bodies in forested catchments on more or less acid-sensitive bedrock and soil. Smaller water bodies are far more numerous than larger ones, and nowadays fish and macroinvertebrate sampling is the dominant biological sampling applied in regular monitoring, at least in the smaller size classes of lakes and streams (Sonesten 2013).

Two of the current standard fish sampling methods (CEN 2003, 2015) evolved from methods that were increasingly used in the 1980's, for monitoring effects of acidification and management of acidified waters by liming. In the 1990's fish monitoring was integrated in national monitoring programs, with regular sampling of water chemistry, phytoplankton, zooplankton and benthic invertebrates (Fölster et al. 2014).

From 1996 fish monitoring data were managed on a national basis on behalf of the Swedish Environmental Protection Agency, and from 2011 steered by the Swedish Agency for Marine and Water Management. The data are currently managed at SLU, within the National Register of Survey Test-fishing (NORS, Kinnerbäck 2015) and the Swedish Electrofishing Register (SERS, Sers 2015), respectively.

The following sections shortly describe the sampling methods and data bases used for inland fish in Sweden (3.1), the fish parameters that are estimated (3.2) and the current official fish assessment methods (3.3). Section 3.3 ends with a few gaps and needs for improvement, identified before 2011. This part forms the basis for summarizing more recent advances in sections 4 and 5, i.e. experiences achieved as part of WATERS and other projects run in parallel.

3.1 Sampling methods

Fish monitoring involve different sampling methods, and a standard method is primarily defined by e.g. sampling gear, effort size, spatial design, season, and time of the day. Each method has its strengths and limitations, including method-specific selectivity for certain species and sizes of fish, thereby influencing observed values of similarly described metrics. In Sweden two main methods have been used in fish sampling for ecological status assessment, i.e. multi-mesh gillnets in lakes and electrofishing in streams. Both methods collect data on species composition, abundance, individual size, and optionally age distributions, although habitat coverage and units of measurements differ.

3.1.1 Multi-mesh gillnets in lakes

In May 2015, the database NORS included 6,197 surveys in 3,596 lakes, using gillnets set over night, during covering the period 1952-2014 (Kinnerbäck 2015). The first multi-mesh gillnets were used from 1968, developed for improved applicability in both benthic and pelagic habitats of small lakes (Hammar and Filipsson 1985, Degerman et al. 1988), as compared to the previous use of larger gillnet gangs (sets of gillnets with different mesh sizes). From1994 onwards most surveys used Nordic multi-mesh gillnets (Appelberg et al. 1995), where benthic gillnets had 12 panels (2.5 m long and 1.5 m high) of bar mesh sizes 5-55 mm, in a geometric series with panel order originally randomized. Whole-lake sampling was temporally standardized to take place in July or August. Minimum numbers of benthic gillnets were specified for quantitative time-series or qualitative inventory sampling, to be set in a depth-stratified design (Appelberg 2000). Additional pelagic sampling was recommended in lakes with more than 10 m maximum depth. Nordic pelagic gillnets were originally 6 m high, with 11 panels of mesh sizes from 6.25 to 55 mm, because the 5 mm mesh panel could not be manufactured for the deeper nets. This Swedish sampling design, including sampling of a pelagic depth profile at the deepest part of the lake, was adopted in the first version of the European standard (CEN 2005).

Among the surveys recorded in NORS, 3,986 refer to whole-lake sampling with Nordic gillnets, following the recommended standard design of time-series or inventory sampling with reduced effort. Surveys were performed in lakes of 1-17,457 ha of surface area and 1-75 m maximum depth, by using 2-128 benthic gillnets and optionally 2-28 pelagic gillnets. Some of the inventory surveys with Nordic gillnets were performed within smaller subareas of larger lakes, including the largest lakes Vänern, Vättern, Mälaren, Hjälmaren and Jämtländska Storsjön. In addition to, or instead of, the original Nordic gillnet, the Nordic coastal multi-mesh gillnet standard that is used in coastal areas of the Baltic Sea (Söderberg et al. 2004, HELCOM 2015) has been increasingly used in the largest lakes during later years (e.g. Beier et al. 2010). The Nordic coastal multi-mesh gillnets perform better in deeper areas, have a larger surface area and slightly larger meshes thus catching more commercially important sizes and species.

3.1.2 Electrofishing in streams

In May 2015, SERS included 57,956 surveys at 17,785 stream sites, conducted by electrofishing during 1951-2014 (Sers 2015). Surveys were done more or less according to the European standard (CEN 2003), as described with further practical guidance by Bergquist et al. (2014). Fishing was done by wading upstream a reach defined by a starting position. The sampling protocol includes description of reach length, width, area, and other attributes of the habitat. The surveys had a median fished area of 188 m^2, with half of the surveys within 106-300 m^2. Qualitative results were achieved in 41% of the surveys, by sampling the reach in a single run. More often multiple runs were performed in the same day, to estimate fish catchability and density in a quantitative way. At least 83% of surveys used straight direct current generated by engine driven equipment, as recommended, instead of the less preferred backpack equipment with pulsed direct current. Most surveys (73%) were done in the recommended time of the year, i.e. August or September.

3.1.3 Other sampling methods

Pelagic fish assemblages in the largest Swedish lakes have been more or less regularly monitored since 1987-1988, by combining pelagic trawling with hydroacoustic echo-counting (Nyberg et al. 2001). These surveys are part of the "Stora Sjöprogrammen", and therefore indirectly part of the national environmental monitoring programs. The management of collected acoustic and trawl data has, however, so far not been a commissioned task for the national fish data host, as for data in NORS and SERS.

Fish in large, deep and/or slow running rivers may be surveyed by e.g. electrofishing from boat and/or by horizontal hydroacoustics. Such methods have been developed in other countries, and some of the methods were once explored and compared in a Swedish pilot study in Rivers Österdalälven and Svartån (Bergquist et al. 2007). Boat electrofishing with mark–recapture methods have also been used in some rivers in Sweden (Carlstein et al. 2005, Carlstein et al. 2006). The most commonly used boat electrofishing method in large rivers is to sample long stretches along both riverbanks. This approach has not, however, been tested in Sweden. Recently sampling in large rivers have instead been conducted with multi-mesh gillnets developed for lotic environments (Johansson 2013, Fjälling et al. 2015). A range of other gear types, e.g. seines, trawls and fyke nets are described in the standard tool box for sampling fish in large rivers in America (Bonar et al. 2009). However, today a standardized method of monitoring fish in the large rivers of Sweden is missing.

3.2 Fish parameters

For the fish fauna in lakes and rivers, indicators are needed to detect and quantify changes attributed to anthropogenic impact for biological parameters such as species composition, abundance and age structure (European Commission 2000). As for other biological quality elements, the fish fauna should be classified as high, good, moderate, poor or bad ecological status, according to Annex V of the WFD. At high status the fish fauna corresponds totally or nearly totally to undisturbed or type-specific reference conditions.

In general terms, a useful ecological indicator should be conceptually relevant, feasible to implement, have known and documented variability, and be possible to interpret and use in environmental decision-making (Jackson et al. 2000). European member states may develop their own indicators, e.g. including different sets of metrics to represent the important fish parameters. National assessment methods, however, need inter-calibration to ensure harmonized reference conditions and status classification for similar water bodies in different countries. The above mentioned rules for useful indicators are, more or less, adopted in the European guidance for inter-calibration (European Commission 2011). The following sections, 3.2.1-3.2.3, shortly describe the fish parameters that need to be assessed and how they can be estimated.

3.2.1 Species composition and sensitive species

As indicated in the introduction, the number and identity of fish species in a certain water body will depend on both natural and anthropogenic factors. The possibility to observe all species present in a lake or stream further depend on sampling effort, habitat coverage and size-selectivity of the sampling gear (e.g. Degerman et al. 1988), implying that we have to deal with method- and scale-dependent indicator values.

Different sets of local taxonomic species may occupy similar niches and have similar ecosystem function, and compared to individual species, functional metrics may be more broadly applicable indicators of composition (e.g. Pont et al. 2006). The simplest way is to categorize species by functional traits related to e.g. adult diet, feeding habitat or reproductive behavior. This might, however, be misleading for communities dominated by species with ontogenetic shifts in diet and habitat use. Species-specific size at niche shift might also be density-dependent (e.g. Byström et al. 2003), and therefore differ between lakes and between years in the same lake.

Fish species composition may be indicated by e.g. the relative proportion of certain species or taxonomic or functional groups, or more generally by species richness or diversity indices based on relative abundance of occurring species. Special attention is paid to occurrence of species sensitive to disturbance, because species differ in preference and tolerance limits along environmental gradients.

3.2.2 Abundance

Fish abundance or density is ideally expressed as numbers or biomass per area or volume of habitat sampled. Abundance per area can usually be estimated at each electrofishing site. Catch per unit of sampling effort (CPUE) is an alternative indicator of abundance, which is generally expressed as the average of all efforts in a small lake, or within certain sub-areas of larger lakes. When sampling with gillnets, the unit of effort is typically one

Nordic gillnet and one night of fishing (ca 12 hours). CPUE is more specifically expressed as numbers or biomass per unit effort (NPUE or BPUE).

Abundance can be expressed separately for each species in the catch or summed over all species to represent the total fish community. Alternative abundance metrics may be calculated for groups of individuals according to e.g. size, age or functional traits as mentioned above.

3.2.3 Age structure

In the normative definitions of the WFD (European Commission 2000), fish age structure has to be used in rivers and lakes as an indicator of failure in the reproduction or ontogenetic development of particular species, e.g. lack of old fish due to overfishing. Less than high status due to anthropogenic disturbance may therefore be indicated by missing age classes. More serious disturbance will lead to several missing age classes, at some stage leading to lower abundance or even extinction of typical species.

Sampling of fish for age determination is optional in the European standards for electrofishing and sampling with multi-mesh gillnets. Age needs to be estimated for individual fish, e.g. by counting annually formed increments on hard structures like scales, bones and/or otoliths (Panfili et al. 2002). Each sample needs preparation before age can be read by a microscope or other optical device. This is a rather time-consuming work, and intercalibration is needed to evaluate bias and precision between different readers and ageing techniques. Data on fish age distributions are therefore lacking for most sampling events in the databases NORS and SERS. In a subset of lakes and even fewer streams, subsampling and ageing has generally been restricted to one or more dominant fish species in the catch, and more occasionally included less abundant species (Holmgren 2013).

In many fish populations, average size tends to increase asymptotically with age, and size may sometimes be inferred as a proxy of age. Some individual fish continue to grow throughout their lives, while others cease to grow after sexual maturity at a young age. Some individuals of most freshwater fish species survive to ages of ten or more, according to age data from gillnet samples in NORS (Holmgren 2013, Kinnerbäck 2013). Median size at similar age differs between species, but also intra-specifically between populations and between and within year-classes in the same lake. A large overlap in length between two, or more, adjacent age groups may occur when most individuals grow far below their size-dependent growth potential (Holmgren and Appelberg 2001), e.g. related to density-dependent competition for food.

In general, growth variation makes size distributions rather poor approximations of age structure. Size of young-of-the year fish (age 0+) may, however, often be well distinguished from older fish. Age 0+ fish are quite efficiently caught by standardized electrofishing in streams (Bergquist et al. 2014), but are often too small or too passive to be caught by standard sampling with Nordic multi-mesh gillnets (Holmgren 2013). In some streams and rivers size of age 1+ salmonid fishes can also be distinguished from older fishes (Bergquist et al. 2014).

3.3 Assessment methods

Literature data on fish species composition, abundance and age structure in relation to pH has been used to biologically infer the lowest pH tolerated by the fish species caught in Swedish monitoring (Degerman and Lingdell 1993). Multi-metric fish indices (FIX for Swedish lakes and streams, respectively) were later developed before implementation of the WFD (Appelberg et al. 1999, 2000). They built on the concept of biotic integrity (Karr 1981), and the idea that fish community structure and function can be successfully used to assess the integrity of water resources. A range of structural and functional metrics were calculated using all fish data in NORS and SERS, and the median values were used to represent the typical reference state.

Further development of the current methods for lakes (Holmgren et al. 2007) and streams (Beier et al. 2007) followed a procedure used to develop a European Fish Index for rivers (EFI, Pont et al. 2006, 2007). The first important step was to collect and match pressure data with data on fish, in order to delimit a set of reference or least impacted sites. Candidate metrics included those earlier used in FIX and EFI, or in an index for coastal streams (Degerman et al. 2005), and additional metrics with expected response to general or specific pressures. The reference dataset was used to calibrate multiple regression models of fish metric response to natural environmental gradients. Observed metric values at all sites were transformed to deviation from predicted (i.e. modelled) values at reference sites. The deviation was standardized to Z-value in the normal distribution, and transformed to probability (P-value), assuming that each metric increased or decreased as response to one or more pressures (i.e. either one- or two-tailed hypotheses). Data from more impacted sites were then used to test metric response to general degradation as well as more specific pressures. Metrics with significant pressure response were checked for collinearity, and a multi-metric index was calculated as the mean of P-values of non-redundant metrics. The boundary between good and moderate status was set at the fish index value with equal probability of misclassification of both reference and impacted sites. Other class boundaries were set at more arbitrarily index values along the cumulative distributions of reference and impacted sites, respectively.

Different sets of pressure variables, environmental factors and fish metrics were used for lake and streams, as specifically summarized in the following sections 3.3.1 and 3.3.2.

3.3.1 Lakes

In 2005, pressure data were externally searched to match 1157 Swedish lakes with fish data from standard sampling with multi-mesh gillnets. pH was most often available (995 lakes), followed by total phosphorous concentration (592 lakes) and land use in the catchment (443 lakes) (Holmgren et al. 2007). A set of 116 reference lakes (i.e. high or good status) was delimited as non-limed lakes with pH > 6, total P < 20 g/L, and/or < 25 % of the catchment covered by agricultural land use and < 1 % by urban land use. Reference values were calibrated for 16 candidate metrics, using five environmental factors as independent variables (altitude, lake area, maximum depth, annual air temperature, and position above or below the highest coastline since last glaciation). All metrics were whole-lake estimates, representing catches in all depth strata sampled by benthic gillnets. Metrics response to pressures, were evaluated by t-tests of differences in Z-values between reference lakes and each of two groups of impacted lakes (40 acidic and 56 nutrient rich lakes). Ten metrics responded significantly to either acidity or nutrient stress, and eight metrics remained (Table 3.1) after exclusion of two redundant metrics (i.e. highly correlated, Pearson's r > 0.8, with other metrics). Class boundaries were set only for the multi-metric index called EQR8, i.e. the mean of P-values for the 3-8 metrics that can be estimated from any standard gillnet survey. The Z-values and signs were, however, suggested as tools for evaluation of metrics response in lakes with low values of EQR8.

TABLE 3.1

Metrics used in the lake fish index EQR8. Signs (+ or -) indicate significant responses to pressures.

Metric	Acidity	Nutrients
1. Number of native fish species	-	+
2. Simpson's D (numbers)	-	
3. Simpson's D (biomass)	-	+
4. Biomass (BPUE) of native species	-	+
5. Abundance (NPUE) of native species	-	+
6. Mean mass (from total catch)		+
7. Biomass proportion of piscivorous percids	+	
8. Ratio perch / cyprinids (biomass)		-

3.3.2 Streams

The current Swedish fish index for streams was developed by using the last electrofishing survey at 601 Swedish sites (Beier et al. 2007). These sites had pressure data already assembled in the EU-project FAME (Degerman et al. 2007), i.e. a subset of the dataset used to develop EFI (Pont et al. 2006, 2007). Separate pressure scores (1-5, where 1 is no or insignificant impact) were thereby available for acidity, eutrophication, morphologic impact, hydrology impact, and connectivity barriers, and 396 sites with no score above 2 were used as references (high or good status). 24 candidate fish metrics were calculated based on one or more runs of electrofishing, i.e. including both quantitative and qualitative surveys. The environmental variables used to calibrate reference values were 1) size class of catchment upstream of the sampling site, 2) class of proportion of lake area in the catchment, 3) least distance to the closest lake upstream or downstream the sampling site (up to 10 km), 4) altitude above sea level, 5) slope, 6) yearly average air temperature, 7) average air temperature during July, 8) wetted width of the stream and 9) sampled area. Additionally, migration type of the trout (resident, lake migrating or sea migrating) was used to adjust the index accordingly. Seven non-redundant metric passed tests of metric response to pressures, and six metrics remained in the final index of general human impact (VIX, Table 3.2), i.e. 1) abundance of salmon and trout, 2) proportion of salmonid species reproducing, 3) proportion of tolerant species, 4) proportion of intolerant species, 5) proportion of lithophilic individuals and 6) proportion of tolerant individuals. Simpson's diversity index was a 7th significant metric, but only for the response to hydrology impact. The metrics 3-5 are also used in the EFI, but then only incorporating data from the first run of electric fishing. The good-moderate boundary was set as described in section 3.3.1, for VIX, as well as for side indices for acidity (VIXs), morphologic impact (VIXm), and hydrology impact (VIXh).

TABLE 3.2

Metrics used in the stream fish index VIX. Signs (+ or -) indicate significant responses to pressures.

Metric	General	Acidity	Nutrients/ organic load	Morph-ology	Hydrology	Connectivity
1. Density of brown trout and salmon	-	-	-	-	-	
2. Proportion tolerant individuals	+		+		+	-/+
3. Proportion lithophilic individuals	-	-	-	-	-	
4. Proportion tolerant species	+		+		+/-	-
5. Proportion intolerant species	-	-	-	-		
6. Proportion salmonids with reproduction	-	-	-	-		
7. Simpson's diversity index					+/-	

3.3.3 Gaps and needs for improvement

Development of EQR8 and VIX suffered from lack of heavily impacted sites in the datasets and data from high altitude lakes and streams (Holmgren et al. 2007, Beier et al. 2007), partly because most Swedish monitoring programs focused on acid-sensitive headwater lakes and streams, and because many acidified water bodies had been regularly limed for decades. Other pressures were less represented in the dataset. There were no data at all to evaluate hydro-morphological pressures in lakes, and just a few stream sites with high impact of water level regulation. For streams there was also a lack of indicators of reduced connectivity (Beier et al. 2007), which is partly related to a need for improved guidance on how many stream sites need to be sampled for assessment at the water body level.

Application of both indices relies on site-specific reference values of included fish metrics, depending on continuous variation of site characteristics. EQR8 and VIX cannot, however, be uncritically applied for sites with characteristics outside the ranges of sites used to calibrate the regression models. For example, the metrics for EQR8 were calibrated for lakes within the following environmental conditions; altitude 10 – 894 m above sea level, lake area 2 – 4,236 ha, maximum depth 1 – 65 m, and annual mean air temperature -2 – 8 °C (Holmgren et al. 2007). In other words, EQR8 was considered less suitable for many small lakes at very low or high altitudes, and for numerically fewer but volumetrically much more important large and deep lakes. Low index values were sometimes observed in reference lakes at high altitude and/or at low yearly mean temperature (Holmgren 2007), partly explained by the fact that two out of eight metrics cannot be calculated, and are not relevant outside the natural distribution area of warm water species like perch (*Perca fluviatilis*), roach (*Rutilus rutilus*) and other cyprinids.

Reference values for metrics of VIX were similarly more or less constrained by ranges of site characteristics in the calibration dataset (Beier et al. 2007). An even more critical assumption was that the site to be assessed should at least historically have been a suitable habitat for brown trout (*Salmo trutta*) and/or salmon (*Salmo salar*), e.g. indicated by a stream slope of less than 50 ‰ and a water velocity above 0.2 m/s. For VIX there is also a general need of improvement concerning its application in streams and rivers not dominated by salmonids, i.e. slow flowing watercourses in agriculture areas (Bergquist et al. 2014).

Some of the early identified gaps are clearly related to limitations of the standard methods used in regular sampling of predominantly rather small lakes and streams in national and regional monitoring programs. The lack of useful fish assessment methods in larger or otherwise outlier water bodies were consequently raised as a serious gap by several county administration boards (Lűcke 2010). Other concerns dealt with low precision of the lake fish index EQR8, and its inability to identify other pressures than acidity or high nutrient levels (Haglund et al. 2010).

4. Recent advances in fish monitoring

Since the development of the current assessment methods for Swedish lakes and streams (Holmgren et al. 2007, Beier et al. 2007), the corresponding standard sampling methods (CEN 2003, 2005) have been continuously used in surveillance and operational monitoring in Sweden and other European countries. According to European guidance (CEN 2006), more than one sampling method might be used in the same water body, depending on varying suitability of any gear type in different habitats. The following sections describe recent use of alternative sampling methods, including selectivity or uncertainty related to one or more sampling methods at different environmental conditions.

4.1 Fish sampling in lakes

The revised standard for sampling with multi-mesh gillnets (CEN 2015) now includes broader options for how to sample the pelagic habitat, i.e. not only to sample a depth profile at the deepest part of lakes with more than 10 m maximum depth. It is now possible to adapt the height of pelagic gillnets, depending on local conditions. It is also possible to use the smaller benthic gillnets also in the pelagic habitat, e.g. to distribute the effort in a stratified design as in the benthic habitat. These extensions reflect and embrace practices developed when the Nordic gillnets were increasingly used in different lake types around Europe (Mehner et al. 2005, Lauridsen et al. 2008, Prchalova et al. 2009a, Specziár et al. 2009, Olin et al. 2013).

In some countries lake fish are sampled by Nordic multi-mesh gillnets together with other sampling methods. For example, the Austrian practice is to use all three European standard methods in combination (Achleiter et al 2012), i.e. Nordic gillnets in benthic and pelagic habitats, electrofishing of shorelines (CEN 2003) and hydroacoustics in the pelagic areas (CEN 2014). Other people have combined gillnetting and electrofishing (Diekmann et al. 2005, Mehner et al. 2005, Sutela et al. 2008, Eros et al. 2009, Menezes et al. 2013), or even gillnetting, electrofishing and low-impact pressure wave sampling using small underwater detonations (Sandström et al. 2014). Some studies combined and compared multi-mesh gillnets with horizontal (György et al. 2012) or vertical hydroacoustics (Emmrich et al. 2012, Yule et al. 2013), or with trawls or seines (Olin et al. 2009, Prchalova et al. 2009b).

Recent method comparisons generally confirm the common view that different sampling methods are complementary rather than perfectly related and exchangeable (e.g. CEN

2006). Combination of sampling gears may result in longer species lists, compared to any single method (Diekmann et al. 2005, Eros et al. 2009, Achleiter et al. 2012), partly because multiple gears more efficiently cover all available lake habitats. Similarly, species lists differed even when comparisons between gillnetting and electrofishing were restricted to the littoral area (Sutela et al. 2008, Sandström et. al. 2014), influencing relative proportions of dominating species.

Abundance estimates from gillnets and hydroacoustics are positively related, when comparing whole lake estimated between lakes (Emmrich et al. 2012), and also when comparing pelagic lake sections within lakes (Yule et al. 2013). Both the smallest and largest sizes of fish in the lakes are underrepresented in gillnet catches compared to size distributions derived from hydroacoustics (Achleiter et al. 2012). Trawls and seines catch small fish more efficiently than gillnets (Olin et al. 2009, Prchalova et al. 2009b). Gillnet panels with larger mesh sizes have been used in addition to the standard Nordic gillnet, to get a better representation of very large fish (e.g. Vašec et al. 2013).

The European interest in better coverage of pelagic fish in the sampling protocol, even in rather shallow lakes, has so far not influenced the Swedish fish monitoring programs. The pelagic of a few very large lakes are regularly sampled at multiple sites, using hydroacoustic and trawling (Sandström et al. 2014). In contrast, only one smaller lake has once been sampled with small, benthic gillnets set at multiple pelagic sites, and fish sampling of almost half of the lakes deeper than 10 m did not include any pelagic sampling sites at all (data in NORS, Kinnerbäck 2015). The inconsistent monitoring of the pelagic habitat was one of the reasons for using only benthic catches in calculation of metrics for the Swedish fish index EQR8.

4.2 Fish sampling in rivers

Electrofishing, as described in the European standard (CEN 2003), is still the most applied sampling method for fish status assessment in Europe. Multiple pass surveys dominate in the Swedish data base SERS, and were also used in several recent national or international river fish studies (Teixeira-de Mello et al. 2012, Clavel et al. 2013, Schmutz et al. 2015). Other assessments relied on single pass surveys (Hermoso et al. 2010), or data from the first run in multiple pass surveys were used to match sites with only single pass surveys (Vehanen et al. 2010). A recent study found 50-100 % of species and 40-60 % of individuals in a single pass (Benejam et al. 2012), with negligible effect of electrofishing crew for assessment of species richness and composition, but considerable for abundance. The spatio-temporal heterogeneity of fish was higher than variability due to electrofishing equipment or operator, when continuous sampling was done at 200 m reaches in a lowland river (Specziár et al. 2012), and methodological factors were less important for species richness and relative abundance, than for CPUE and mean size for certain species. Alternatively, point abundance sampling may be more cost effective than continuous electrofishing in lowland rivers (Janac and Jurajda 2007, Copp 2010, Tomanova et al. 2013), especially when surveying young fish.

Long term fish monitoring in large Swedish rivers are mainly performed as part of anadromous fish management (e.g. Palm et al. 2014), where young salmon and trout are monitored by electrofishing at their spawning grounds in wadeable parts of the river. In some cases boat electrofishing and mark-recapture methods have also been used to monitor salmonid fishes such as grayling and salmon (Carlstein et al. 2005, Carlstein et al. 2006). Further, a Swedish pilot project surveyed fish assemblages in larger and deeper river reaches by strip-fishing using boat electrofishing (according to Schmutz et al. 2001) and horizontal hydroacoustics (Bergquist et al. 2007). Both methods gave quantitative and reproducible measures of fish abundance, and together provided information about species composition and size distributions. Limited access to electrofishing boats and acoustic devices in Sweden is a main reason for limited use of this monitoring approach.

More recent efforts to sample fish assemblages in deeper rivers were made by using multimesh gillnets developed for lotic environments (Fjälling et al. 2015), i.e. the Norden multimesh Stream Survey Net (NSSN). Mesh-size composition mimicked the Nordic gillnet used for standard sampling of fish in lakes, i.e. 12 panels with mesh sizes of 5-55 mm, but each with lower height (0.7 m) and length (1.5 m) than the standard benthic gillnets for lakes. When used together with fyke nets in a small but slow flowing river, catch per unit effort of the five most numerous fish species did surprisingly not differ between the two different gear types (Fjälling et al. 2015).

In a comparative study in River Klarälven (Johansson et al. 2012), NSSN caught 13 fish species and boat electrofishing caught 18 fish species. Within WATERS a first protocol was suggested on how to apply NSSN in river fish monitoring (Bergquist 2014), and last year NSSN was used along with electrofishing from boat and electrofishing by wading from shores in rivers Ätran and Högvadsån. In this study NSSN caught more species than each of the two electrofishing methods (Spjut et al. in preparation). The mean size of fish caught differed between methods, with the smallest fish caught with electrofishing by wading and NSSN caught fish with the largest mean size. The contrasting resulting results in method-specific estimates of species richness are possibly related to differences in local conditions, indicating need for further studies in more rivers.

5. Recent advances in status assessment

At the European scale, electrofishing data from rivers were used in national assessment methods, compiled in a European database, and a common European fish index (EFI) was developed and refined far before the WATERS project started in 2011 (FAME CONSORTIUM 2004, EFI+ CONSORTIUM 2009). The Swedish index VIX was one of the first 13 national methods compared with the sum of ten metrics in EFI (Jepsen and Pont 2007). VIX later passed the second phase of inter-calibration (European Commission 2013), along with another eleven national river fish assessment methods.

In contrast, a similar European database of lakes sampled with multi-mesh gillnets was compiled more recently, hereafter called the IC/WISER dataset. The first lake fish index at the European scale (Argillier et al. 2013) was developed as part of the EU project WISER (Hering et al. 2013), and partly in parallel to the Swedish WATERS project. The performance of the Swedish index EQR8 was compared with lake fish methods of other Nordic countries (Sairanen et al. 2008, Holmgren et al. 2010, Olin et al. 2014). So far only two methods in the Nordic inter-calibration group and three methods in the alpine group fulfilled all criteria for successful inter-calibration (European Commission 2013, Poikane et al. 2014). However, this formal inter-calibration decision did not comprehend EQR8 (see more details in section 5.1.2).

Inter-calibration is important for comparable assessment of ecological status in relation to common pressures within common water body types at European or ecoregion scales (Poikane et al. 2014). Successful inter-calibration does not, however, guarantee acceptable performance in relation to all relevant pressures in all water body types at national and sub-national scales. Moreover, fish metrics and indices responding to large-scale pressures may not assess status of species composition, abundance and age structure at a smaller scale, i.e. the local water body scale.

The following sections describe recent findings about fish metrics in relation to environmental gradients, inter-calibrated fish assessment methods, and suggested complements to current Swedish assessment methods for lakes and streams, respectively.

5.1 Lakes

Within WATERS, large efforts were spent on acquiring physical and chemical data for use in a revised pressure filter, i.e. to split fish (and other biological) datasets into minimally disturbed (reference) and stressed sites, respectively (Johnson et al. 2014). Refined pressure variables were matched with lakes in NORS with whole-lake standard sampling for fish during 2000-2013, although with limited success. Out of 598 non-limed lakes in the fish dataset, only 21 reference lakes and 290 stressed lakes were identified, whereas 287 lakes (48 %) had missing values in some or many pressure variables. With only 21 strictly defined reference lakes, no further attempt was made so far to calibrate new models for estimation of fish metrics at site-specific reference conditions. Further progress will rely on a modified, less restrictive pressure filter, or need to consider other ways of defining reference conditions. A current attempt to develop common metrics for fish in Swedish and Norwegian lakes (Holmgren 2014) considers using the simpler and less restrictive reference filter developed for use at the European level (Caussé et al. 2011).

Since WATERS started in 2011, our Swedish fish data in the IC/WISER dataset were repeatedly analyzed together with corresponding data from other EU countries, for intercalibration of national assessment methods (Olin et al. 2014), for development of common metrics and indices (Argillier et al. 2013), and for more basic studies of factors influencing variation in fish assemblages at different geographical scales (Brucet et al. 2013, Emmrich et al. 2014, Arranz et al. 2015, Mehner et al. 2016).

5.1.1 Fish metrics and environmental gradients

The international IC/WISER dataset covered longer gradients of e.g. eutrophication than the Swedish dataset previously used to develop the fish index EQR8. This dataset was used for development of European fish metrics and indices. A strict procedure excluded most of the 90 candidate metrics, because of small ranges or extreme outliers, insignificant response to pressures, or high correlation with other metrics. Only two or three out of many tested metrics passed all criteria and steps to be included in a European or a Nordic fish index, significantly decreasing with increasing non-natural land use in the catchments, or with increasing total phosphorus concentration, respectively (Argillier et al. 2013, Figure 5.1). Total fish abundance (NPUE) and biomass (BPUE) were included along with NPUE of omnivorous fish in the European index, while total NPUE and NPUE of fish with benthic living and feeding habitat were the two metrics in the Nordic index. NPUE of benthic fish decreased with increasing eutrophication pressure, and the other metrics increased. Within WATERS, we unfortunately failed to apply the new indices on data from Swedish lakes in the database NORS. Both indices use regression models for hindcasting references values of included metrics. Some environmental factors in the models are not easily available for all Swedish lakes, e.g. catchment area and non-natural land-cover. There are also some non-resolved questions concerning errors in the published coefficients (Table 5 in Argillier et al. 2013) needed to calculate the site-specific reference values.

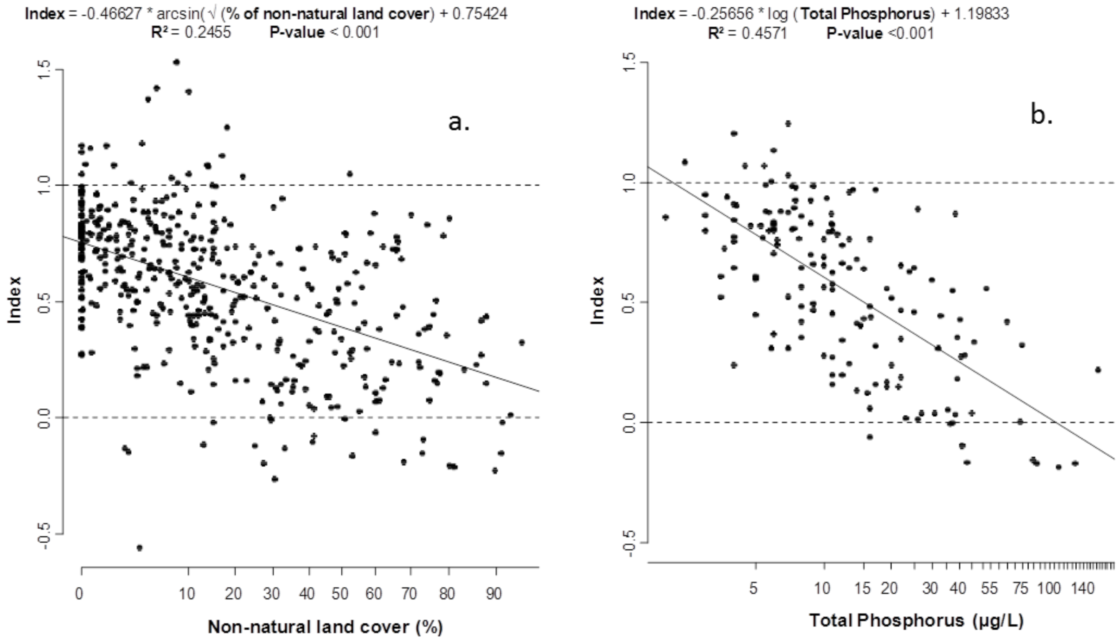

FIGURE 5.1

Response of two fish indices to eutrophication pressure, i.e. a) index using the European dataset in a gradient of % non-natural cover in the catchment, and b) index using the Nordic dataset in a gradient of total phosphorous (µg/L). This figure is modified from Argillier et al. (2013).

Another European study found that NPUE and BPUE increased as expected with total phosphorus, but at the same phosphorus level there was more fish in warmer compared to colder lakes (Brucet et al. 2013, Figure 5.2). Effects of eutrophic conditions on species diversity and size structure were harder to distinguish from geographic and climate-related factors at the European scale. In contrast, size spectra were significantly flatter and size diversity was higher in deep, less nutrient-rich lakes at a regional scale in northern Germany (Emmrich et al. 2011).

At the European scale, fish size structure differed between lakes dominated by fish in different temperate guilds (Emmrich et al. 2014), i.e. either perch or cyprinids in warmer water or salmonids in colder water. Fish mean body size tended to decrease with increasing temperature, for the whole dataset, as well as for subsets categorized by ecoregion or by fish thermal guild (Figure 5.3). The size spectrum had more negative slopes at higher temperature, implying high density of small, and possibly young, fish rather than lack of larger fish. Similar size-temperature relationships appeared within three of the six most frequently occurring fish species (Arranz et al. 2015). Increasing inter- or intra-specific fish density were, however, even more general predictors of decreasing mean size, size diversity or slope of size spectra for all six species. Analysis on fishes split into piscivores, nonpiscivores or prey of piscivores, further supported the importance of competition as a source of between-lake variability in fish density and size (Mehner et al. 2016).

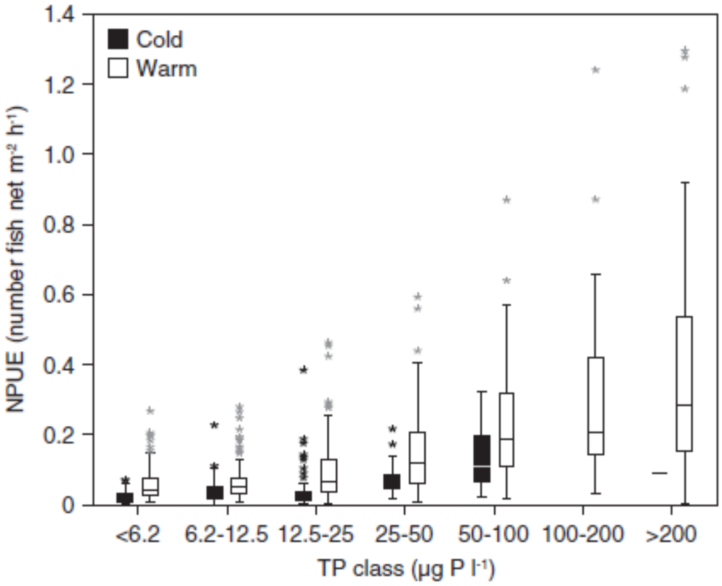

FIGURE 5.2

Fish abundance (NPUE) in lakes of different classes of total phosphorous (µg/L), further categorized as cold (July air temperature < 15 °C) or warm (July air temperature > 15 °C). This figure is modified from Brucet et al. (2013).

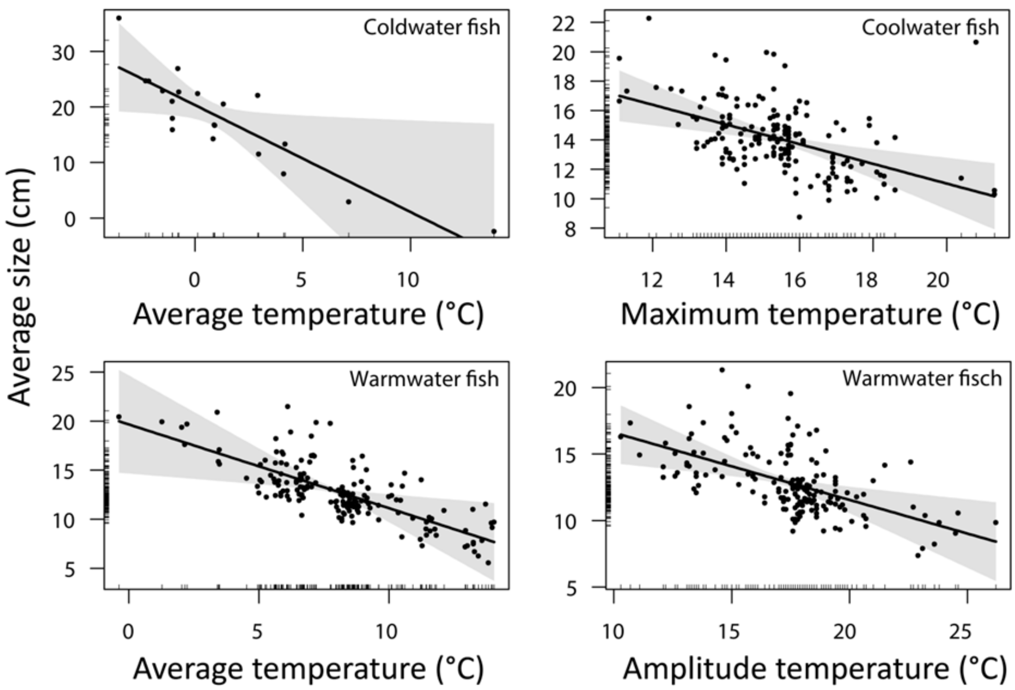

FIGURE 5.3

Mean body size (cm) in response to different measures of temperature, for groups of lakes with numerical dominance of coldwater, coolwater and warmwater fish. This figure is modified from Emmrich et al. (2014).

Age data from a smaller subset of Swedish lakes showed that fish size to a less extent reflect age structure of frequently occurring species (Holmgren 2013). Age-based fish metrics might therefore be more suitable than pure size metrics for assessment of acidification or for monitoring trends in a changed climate. Back-calculated age after the first growth season seems to be useful in this sense (Jeppesen et al. 2012), because biotic factors introduce density-dependent growth to a larger extent at higher ages.

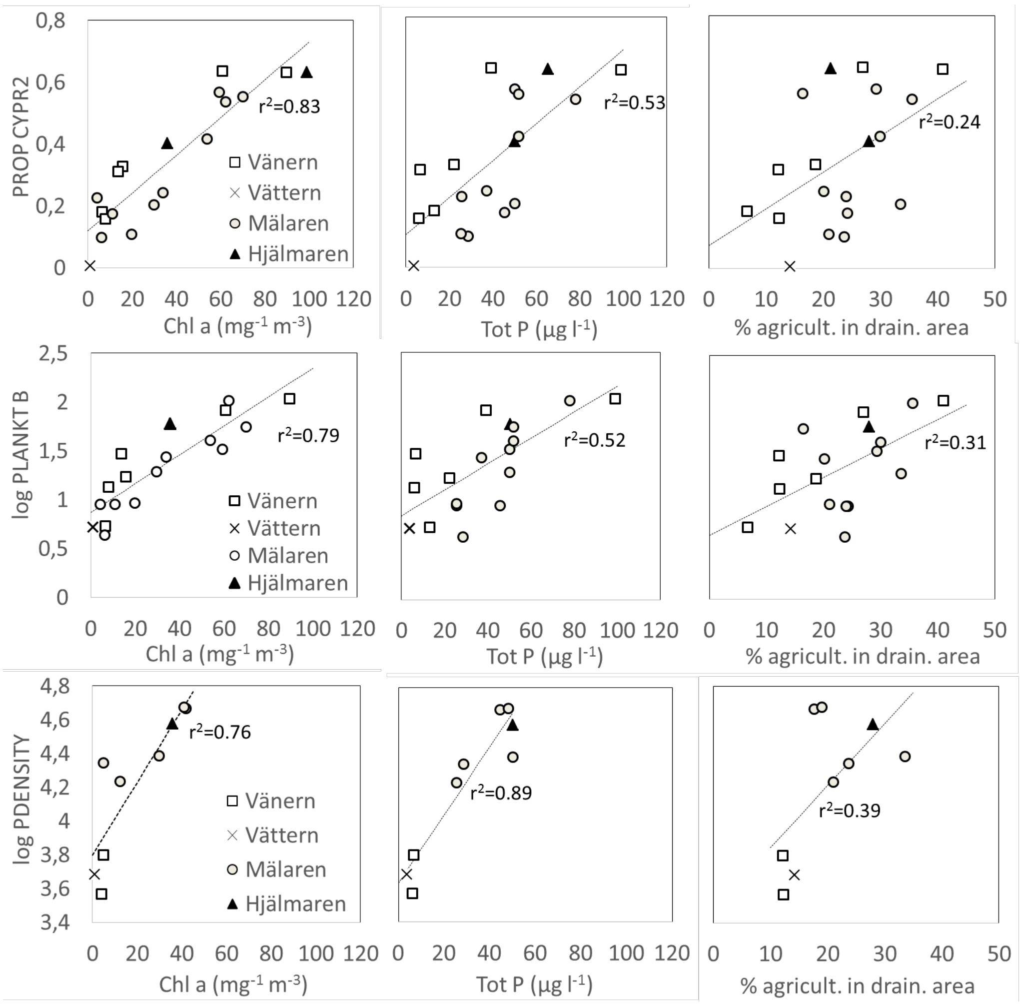

FIGURE 5.4

Three fish metrics respond to gradients in chlorophyll a (Chl a), total phosphorous (Tot P), and % agriculture in the drainage area (PDENSITY = density of pelagic fishes, PLANKT B = biomass of planktivorous species, and proportion of cyprinids (when excluding roach). Observations refer to water bodies within the largest Swedish lakes. This Figure is from Sandström et al. (submitted)

A recent Swedish study compiled fish data from sampling with gillnets, hydroacoustics and trawling in the four largest lakes of Sweden (Sandström et al., submitted). Maps of remote sensing data describing chlorophyll a, total suspended matter and dissolved organic matter were overlaid on all available fish data. A range of fish metrics were calculated for different water bodies within each of the lakes. Density of pelagic fishes, biomass of planktivorous species, and proportion of cyprinids (when excluding roach) appeared as most useful for assessment of eutrophication pressure, as all of them increased significantly with increasing chlorophyll a, total phosphorous and % agriculture in the drainage area (Figure 5.4).

5.1.2 Inter-calibrated assessment methods

Two of four national assessment methods passed all steps in the Nordic inter-calibration group (Olin et al. 2014), i.e. the methods developed for use in Finland (EQR4, Olin et al. 2013) and Ireland (FIL2, Kelly et al. 2012). Both methods were multi-metric indices developed and tested with eutrophication as pressure, but they differed in typology, in fish metrics included and in statistics for calculation and testing. Originally, the Finnish method was developed based on data from multi-mesh Nordic gillnets used in benthic and pelagic habitats, while the Irish method additionally depended on data from fyke nets. In the inter-calibration exercise both methods were applied to benthic gillnet catches from non-acidified lakes in four Nordic countries, fitting the descriptions of two out of twelve Finnish lake types. A Norwegian Fish Index (FCI, Direktoratsgruppa Vanndirektivet 2009) was excluded from the final inter-calibration because of too different assessment concept. It relies on detailed knowledge of temporal change in local species occurrence and dominance relationships, rather than deviance from reference values derived by averaging or modelling observations from recent samples at the least impacted sites. The Swedish EQR8 was also excluded. It was not significantly related to the Finnish and Irish methods, at least not when applied to lakes in the other Nordic countries (Figure 5.5).

We previously knew that EQR8 responded stronger to acidity than to high nutrient levels (Holmgren et al. 2007). Fish abundance decreases with increasing maximum depth and altitude. When using these factors to calculate reference values, we might unintentionally compensate for shared variation with total phosphorous, thereby weaken the response to eutrophication pressure. The Swedish models for calculation of site-specific reference values of EQR8-metrics might be less relevant for lakes in the other Nordic countries. For example, at a certain level of % agriculture in the catchment, total phosphorous concentration is higher in Finnish lakes, and lower in Norwegian lakes, as compared to Swedish lakes (Holmgren et al. 2010). The exclusion of non-native fish species in calculation of several metrics (Table 3.1) posed further problems when applying EQR8 to Irish lakes (Holmgren et al. 2010), where non-native perch and cyprinid species often comprise a considerable part of local fish communities.

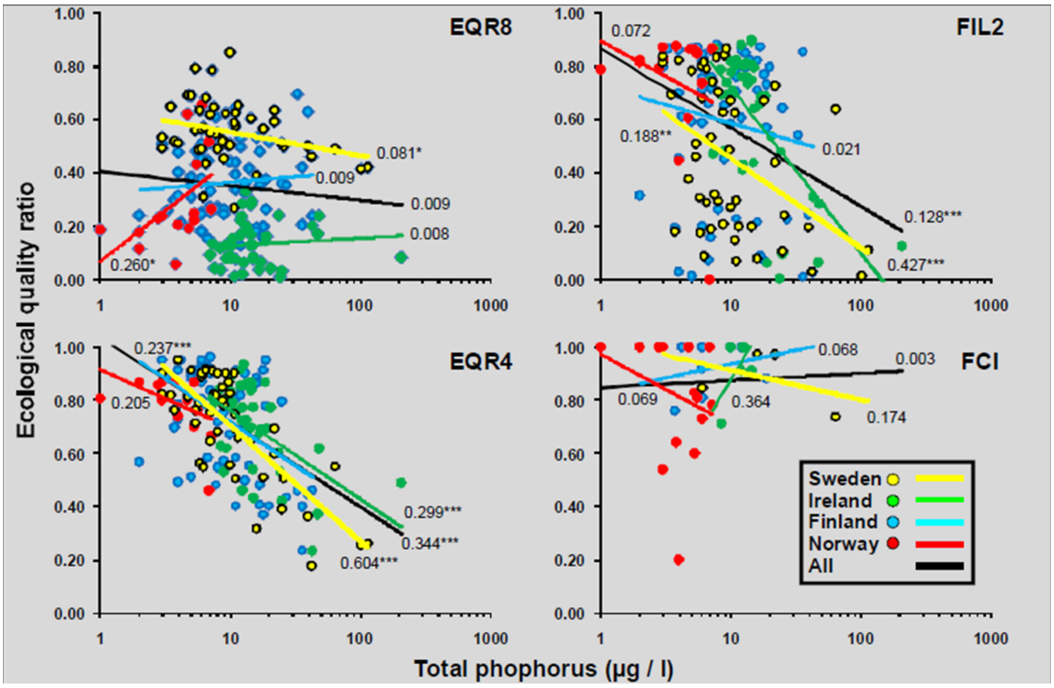

FIGURE 5.5

EQR's of four national methods (Swedish EQR8, Finnish EQR4, Irish FIL2 and Norwegian FCI) in relation to total phosphorous concentration, when applied to all lakes or separately for lakes in each country. Values represent determination coefficients (R^2), and asterisks indicate significant regressions. Modified figure from Olin et al. (2014).

For an assessment method based on site-specific reference values (as EQR8) to work optimally in neighboring countries, the reference values should preferably be re-calibrated to gradients in relevant natural predictors in all countries involved. A bilateral collaboration recently resulted in a new fish index for assessment of ecological potential in French and Czech reservoirs (Blabolil et al. 2016). A similar approach will be used in 2016 for possible development of common metrics or a new fish index for Swedish and Norwegian lakes (Holmgren 2014). This work we will be facilitated by the recent collection of pressure data for Swedish lakes that was done in the WATERS project.

Apart from the Nordic group, there was also some successful inter-calibration between lake fish methods used in the alpine parts of Austria, Italy and Germany (Gassner et al. 2014). The three alpine methods used between five and nine fish metrics. The fish indices responded to a pressure index, combining pressures like eutrophication, water level fluctuation, shoreline modification, lack of connectivity, fisheries, recreation and alien or translocated species.

5.1.3 Suggested metrics and/or assessment methods

There are at present no generally applicable alternative to the current fish index EQR8, for use in small lakes with whole-lake sampling by Nordic multi-mesh gillnets. Sometimes more relevant metric values may be achieved by critical adjustment of modelled reference values, e.g. when there are empirical evidence for only one fish species in the reference state of high mountain lakes (Holmgren 2013). Age determination will increase the possibilities to detect irregular recruitment of e.g. roach in acidified lakes. As indicated in section 5.1.2, an ongoing collaboration with Norway will potentially render new common metrics for use in two countries.

The Finnish index EQR4 might be a suitable alternative for lowland lakes in northern Sweden (Sairanen et al. 2008), where acidification is not a relevant pressure. The four metrics included are total BPUE, total NPUE, cyprinid biomass proportion and indicator species (Olin et al. 2013). The first three metrics are evaluated in relation to reference values within different Finnish lake types, depending on mean depth, water color and lake area. The fourth metric, presence of indicator species, is defined differently for lakes smaller or larger than 200 ha.

Density of pelagic fishes, biomass of planktivorous species, and proportion of cyprinids (when excluding roach) should be further explored for application in the very largest lakes (Sandström et al., submitted manuscript).

5.2 Rivers or streams

Within WATERS, we had great difficulties in applying the revised pressure filter to electrofishing sites in the database SERS. Variables for the pressure filter were compiled at the water body level, and many electrofishing sites could not easily be assigned to the water bodies defined in the Water Information System of Sweden (VISS). The water body identity is not included as a variable in SERS, and we had no useful GIS-tool for automatic matching of all electrofishing sites. A more manual site-by-site match was, however, used in a study on fish response to altered hydrological regime (Spjut and Degerman 2015a).

The following sections summarize experiences from a number of recent studies on fish in streams and larger rivers, from different projects run in parallel to the WATERS project. They all addressed stream fish response to hydro-morphological pressures. Some of them used data from electrofishing by wading at stream sites in SERS, while one used the novel Norden multi-mesh Stream Survey Net (NSSN, Fjälling et al. 2015).

5.2.1 Fish metrics and environmental gradients

River regulations by large dams are known to favor or disfavor fish with different life history strategies (e.g. Mims and Olden 2013). High hydrological variability may be a more important process than aspects of low water flow (e.g. Crow et al. 2013). Very high variation in fish abundance was observed between years at Swedish electrofishing sites with high inter-annual variation in water level (Degerman et al. 2013). This study was part of the HYMO-project, investigating hydromorphologic impact through collaboration between county administration boards. VIXh responded reasonably well to water level regulation at the local scale (Figure 5.6). VIXh was compared to three alternative fish indices of hydrological pressure (Degerman et al. 2013). A first pressure index (Pi1) was based on predefined classification of fish species in three functional groups (stream fish, lake fish, and fish with intermediate habitat preference). Presence/absence and abundance of fish species in the specific dataset was used to identify salmonids as disfavored and perch, Northern pike, roach, burbot and bullheads as favored by water level regulation. These groups were used in a logistic regression to express a second pressure index (Pi2) as the predicted probability of water level regulation. Finally, reference values were modeled for density of salmonids and fish favored by regulation, respectively, and observed residuals at any site were used in a new index called RIX (Degerman et al. 2013). The study concluded that the regionally developed RIX had higher precision than VIXh in detecting sites affected by water level regulation. It was recommended to include samples from at least three years in the assessment, to decrease the risk of misclassification.

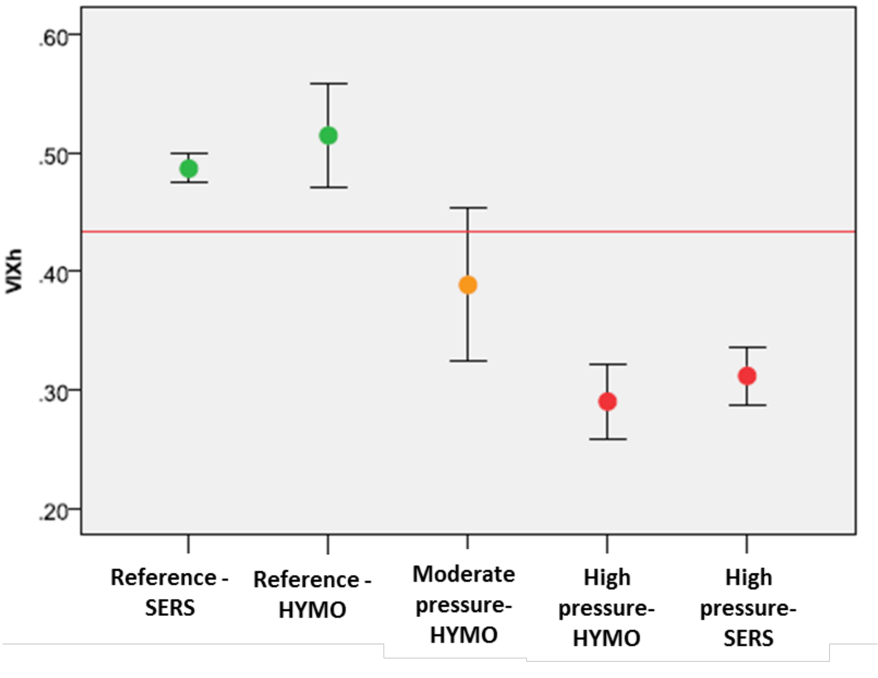

FIGURE 5.6

Mean VIXh (+ 95 % c.i.) for groups of electrofishing sites, assigned as references, or as moderately or highly affected by water level regulation. Information on reference state or pressure level refers to data in SERS or data from the HYMO-project, respectively. This figure is modified from Degerman et al. (2013).

Another study used a nationally GIS-layer with information on water level fluctuations, and applied the new Swedish assessment criteria for hydrological regime (Havs- och vattenmyndigheten 2013). A total number of 1675 electrofishing sites in SERS were used to find out which fish species were favored or disfavored by altered hydrological regime (Spjut and Degerman 2015a). Both favored and disfavored fish and crayfish showed clear response to increased hydrological pressure (Figure 5.7). The species assigned to each groups differed depending on using species occurrence or density as response metric. The fish species assigned to each group also showed some unexpected patterns, e.g. an increase in occurrence and density of brown trout at disturbed sites. At a subset of sites from the HYMO-project, there was low correspondence between the GIS-based assessment of hydrological regime at sub-catchment level and the hydrological pressure assessed at local scale. The hydrological pressure at sub-catchment scale was therefore a poor predictor of direct hydrological pressure at the electrofishing sites, and it was not possible to develop any new index of hydrological pressure for use at the national scale.

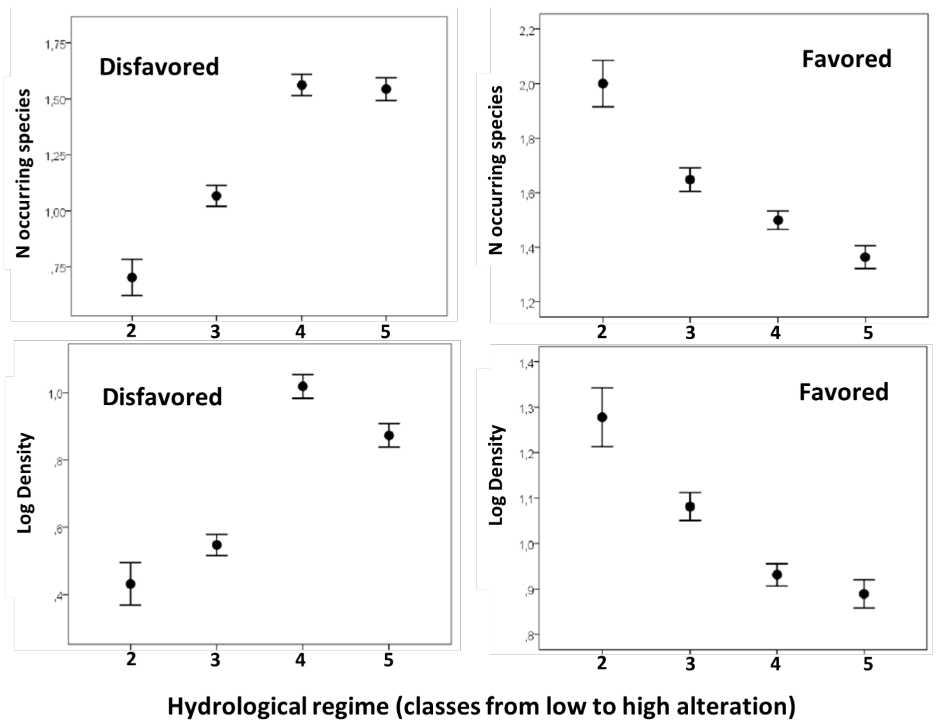

FIGURE 5.7

Response of species disfavored or favored by alteration of hydrological regime. Mean values (+ 95 % c.i.) of number of occurring species, or log density of fish, are shown for groups of electrofishing sites with poor (2), moderate (3), good (4) or high (5) status in hydrological regime. This figure is modified from Spjut and Degerman (2015a).

A refined fish index of morphological pressure (VIX_{MORF}) was developed by using data from river habitat surveys in three counties (Spjut and Degerman 2015b), and the response of VIX_{MORF} was then validated against estimates of morphological pressures made by the field staff when performing electrofishing by wading. In both cases, the morphological pressure was clearance from stones and/or straightening/channelization of the streams. The new index VIX_{MORF} included seven metrics. Five metrics decreased with pressure, i.e. density of brown trout, density of rheophilic species (preferring fast moving water), proportion of rheophilic individuals, number of rheophilic species and number of species disfavored by morphologic alteration. In contrast, both the density and the proportion of species favored by alteration first decreased and then increased at higher levels of alteration. A boundary between good and moderate status was set at the VIX_{MORF}-value with equal probability of correct classification of both impacted and reference sites (VIX_{MORF} = 0.467, Figure 5.8), as previously done for VIX and its side index VIX_M for morphological impact (Beier et al. 2007). The validation against morphological pressures, recorded in SERS (by electrofishing staff), indicated that VIX_{MORF} did not detect impact from clearance for timber transport was less well impact from other clearance from stones and channelization (Figure 5.9).

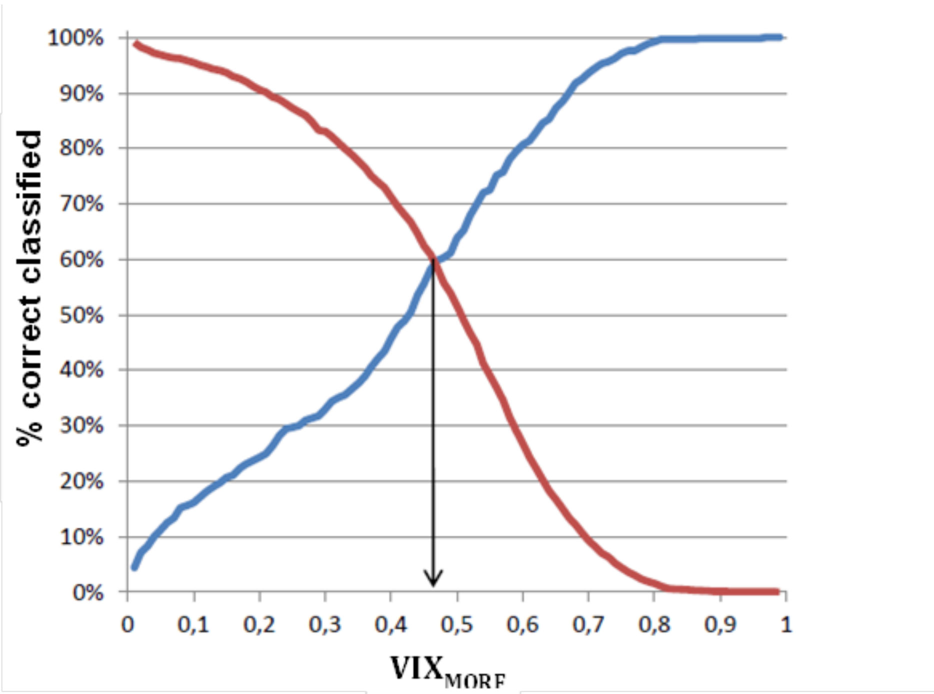

FIGURE 5.8

The proportion of correct classified electrofishing sites along the range of possible values of VIX_{MORF}. Blue curve for reference and red curve for morphologically impacted sites. The vertical line is set at the intersection of curves correspond to VIX_{MORF} = 0.467. Figure modified from Spjut and Degerman (2015b).

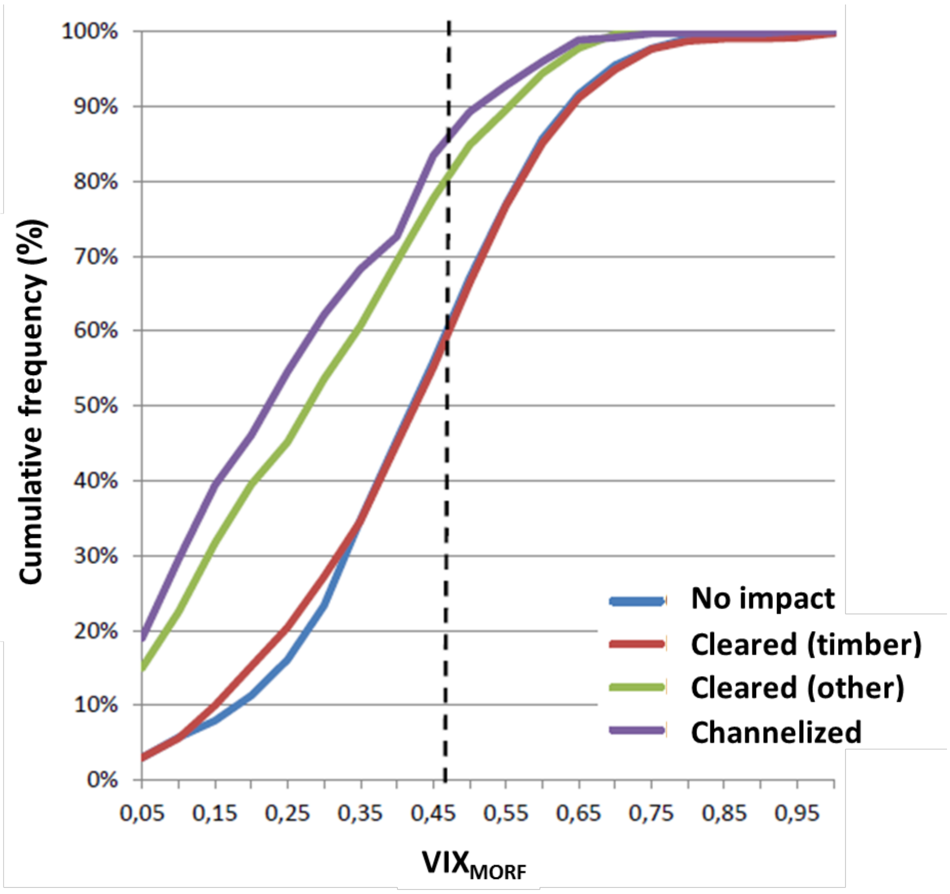

FIGURE 5.9

The cumulative frequency of electrofishing sites with no impact or different categories of morphologic impact as recorded in SERS. The vertical line is set at VIX_{MORF} = 0.467, i.e. the suggested boundary between good and moderate status. Figure modified from Spjut and Degerman (2015b).

Similarly, abundance of rheophilic species decreased and limnophilic species (preferring standing water) increased with increasing channelization in the rivers Gavleån and Testeboån (Johansson 2013), were fish was sampled with NSSN.

5.2.2 Inter-calibrated assessment methods

As already mentioned, the Swedish fish index VIX passed the second phase of inter-calibration (European Commission 2013). Among the other eleven inter-calibrated river fish methods, there are mixtures of multi-metric indices using type-specific reference values (e.g. Vehanen et al. 2011) or site-specific reference values similar to VIX (e.g. Oberdorff et al. 2002). Whenever a national assessment method is inter-calibrated, there is no formal need to develop additional methods. There has, however, been continued development, e.g. to improve assessment in species-poor systems (Hermoso et al. 2010, Loges & Pont 2011).

5.2.3 Suggested metrics and/or assessment methods

Several recent Swedish studies indicate that VIX, and its pressure-specific side indices (VIXs, VIXm and VIXh) work reasonably well, but alternative indices have higher precision in detecting sites with hydrological or morphological alterations (Degerman et al. 2013, Spjut and Degerman 2015a, b). The improvements involved classification of fish species into new functional groups, i.e. species favored or disfavored by certain pressures at relevant geographical scales, instead of the previously used general classification of some fish species as tolerant or intolerant (FAME CONSORTIUM 2004). The new indices RIX and VIX_{MORF} were developed for use at wadeable electrofishing sites, but similar concepts might be used for river sites sampled by other methods. More rigorous tests of RIX and VIX_{MORF} would be possible if relevant pressure data became available for more stream water bodies and local electrofishing sites, e.g. by more investigations using the Swedish river habitat survey (Naturvårdsverket 2003).

6 Acknowledgments

The present collection of information on ongoing work on inland fish as part of or in parallel to the WATERS project was greatly facilitated by regular meetings and e-mail-communication within a group of inland fish experts at the Institute of Freshwater Research. The following persons added valuable input during different parts of the 5-years project; Ulrika Beier, Björn Bergquist, Magnus Dahlberg, Erik Degerman, Anders Kinnerbäck, Leonard Sandin, Alfred Sandström and David Spjut. Drafts of this report were improved by specific adjustments suggested by the members of the group. Thanks to all of you, especially to Björn, Alfred and Leonard for your thorough input to the last version. Stina Drakare and Mats Lindegarth provided additional and very valuable comments from a more external view.

7 References

Abell, R., Thieme M.L., Revenga C., Bryer M., Kottelat M., Bogutskaya N., Coad B., Mandrak N., Balderas S.C., Bussing W., Stiassny M.L.J., Skelton P., Allen G.R., Unmack P., Naseka A., Rebecca N.G., Sindorf N., Robertson J., Armijo E., Higgins J.V., Heibel T.J., Wikramanayake E., Olson D., Lopez H.L., Reis R.E., Lundberg J.G., Sabaj Perez M.H. & Petry P. (2008). Freshwater Ecoregions of the world: a new map of biogeographic units for freshwater biodiversity conservation. Bioscience, 58:403-414.

Achleitner, D., Gassner, H. & Luger, M. (2012). Comparison of three standardised fish sampling methods in 14 alpine lakes in Austria. Fisheries Management and Ecology, 19:352-361.

Appelberg, M. (editor) (2000). Swedish standard methods for sampling freshwater fish with multi-mesh gillnets. Fiskeriverket Information, 2000:1, 35 p.

Appelberg, M., Berger H.-M., Hesthagen T., Kleiven E., Kurkilahti M., Raitaniemi J. & Rask, M. (1995). Development and intercalibration of methods in Nordic freshwater fish monitoring. Water, Air and Soil Pollution, 85:401-406.

Appelberg, M., Bergquist, B.C. & Degerman E. (1999). Fisk. Pp. 167-239 in: Wiederholm, T. (editor). Bedömningsgrunder för miljökvalitet. Sjöar och vattendrag. Bakgrundsrapport 2. Biologiska parametrar. Naturvårdsverket Rapport, 4921. (In Swedish)

Appelberg, M., Bergquist, B.C. & Degerman, E. (2000). Using fish to assess environmental disturbance of Swedish lakes and streams – a preliminary approach. Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie, 27:311-315.

Argillier, C., Caussé, S., Gevrey, M., Pédron, S., De Bortoli, J., Brucet, S., Emmrich, M., Jeppesen, E., Lauridsen, T., Mehner, T., Olin, M., Rask, M., Volta, P., Winfield, I.J., Kelly, F., Krause, T., Palm, A. & Holmgren, K. (2013). Development of a fish-based index to assess the eutrophication status of European lakes. Hydrobiologia, 174:193-211.

Arranz, I., Mehner, T., Benejam, L., Argillier, C., Holmgren, K., Jeppesen, E., Lauridsen T.L., Volta P., Winfield, I.J. & Brucet, S. (2015). Density-dependent effects as key drivers of intraspecific size structure of six abundant fish species in lakes across Europe. Canadian Journal of Fisheries and Aquatic Sciences, 72:1-16, dx.doi.org/10.1139/cjfas-2014-0508.

Beier, U., Andersson, M., Johansson, M., Sandström, A. & Axenrot, T. (2010). Provfiske i Mälaren 2009. Pp. 123-149 in: Andersson, H.C. (editor). Fisk i vattendrag och stora sjöar. Metoder för övervakning. Länsstyrelsen i Stockholms län, Rapport, 2010:7. (In Swedish)

Beier, U., Degerman E., Sers B., Bergquist B. & Dahlberg, M. (2007). Bedömningsgrunder för fiskfaunans status i rinnande vatten – utveckling och tillämpning av VIX. Environmental quality criteria to determine the status of fish in running waters – development and application of VIX Fiskeriverket Informerar, 2007:5, 59 p. (In Swedish with English summary)

Benejam, L., Alcaraz, C., Benito, J., Caiola, N., Casals, F., Maceda-Viega, A., de Sostoa, A. & García-Berthou, E. (2012). Fish catchability and comparison of four electrofishing crews in Mediterranean streams. Fisheries Research, 123-124:9-15.

Bergquist, B. (2014). Provfiskeförsök med strömöversiktsnät under 2014. Förslag på undersökningobjekt och försöksupplägg. PM 2014-06-24, 19 p.

Bergquist, B, Axenroth, T., M. Carlstein & Degerman, E. (2007). Fiskundersökningar i större vattendrag. Utveckling av kvantitativ metodik med båtelfiske och hydroakustiska metoder – ett pilotprojekt. Fiskeriverket Informerar, 2007:10, 50 p. (In Swedish with English summary)

Bergquist, B, Degerman, E., Petersson, E., Sers, B., Stridsman, S. & Winberg, S. (2014). Standardiserat elfiske i vattendrag. En manual med praktiska råd. Aqua Reports 2014:15, 165 p. (In Swedish with English summary)

Blabolil, P., Logez, M., Ricard, D., Prchlova, M., Riha, M., Sagouis, A., Peterka, J., Kubecka J. & Argillier, C. (2016). An assessment of the ecological potential of Central and Western European reservoirs based on fish communities. Fisheries Research, 173:80-87.

Bonar, S.A., Hubert, W.A. & Willis, D.W. (editors). (2009). Standard methods for sampling North American freshwater fishes. American Fisheries Society, Bethesda, Maryland. 335 p.

Brucet, S., Pédron, S., Lauridsen, T.L., Mehner, T., Argillier, C., Winfield, I.J., Volta, P., Emmrich, M., Hesthagen, T., Holmgren, K., Benejam, L., Kelly, F., Krause, T., Palm, A., Rask, M. & Jeppesen, E. (2013). Fish diversity in European lakes: geographic predictors dominate over anthropogenic pressures. Freshwater Biology, 58:1779-1793.

Byström, P., Persson, L., Wahlström, E. & Westman, E. (2003). Size- and density-dependent habitat use in predators: consequences for habitat shifts in young fish. Journal of Animal Ecology, 72:156-168.

Carlstein, M., Broberg, J. & Bruks, A. (2006). Beståndsuppskattning och inventering av laxfisk i Klarälven 2006. Rapport Fiskeresursgruppen, Älvdalens utbildningscentrum. 13 p. (In Swedish)

Carlstein, M., Bruks, A. & Broberg, J. (2005). Beståndsuppskattning och inventering av laxungar i Vindelälven 2005. Rapport Fiskeresursgruppen, Älvdalens utbildningscentrum. 13 p. (In Swedish)

Caussé, S., Gevrey, M., Pédron, S., Brucet, S., Holmgren, K., Emmrich, M., De Bortoli, J. & Argillier, C. (2011). WISER Deliverable 3.4-4: Fish indicators for ecological status assessment of lakes affected by eutrophication and hydromorphological pressures. http://www.wiser.eu/download/D3.4-4.pdf.

CEN. (2003). Water quality – sampling of fish with electricity. European standard. European Committee for Standardization. Ref. No. EN 14011:2003.

CEN. (2005). Water quality – sampling of fish with multi-mesh gillnets. European standard. European Committee for Standardization. Ref. No. EN 14757:2005.

CEN. (2006). Water quality – guidance in the scope and selection of fish sampling methods. European standard. European Committee for Standardization. Ref. No. EN 14962:2006.

CEN. (2014). Water quality – guidance on the estimation of fish abundance with mobile hydroacoustic methods. European standard. European Committee for Standardization. Ref. No. EN 15910:2014.

CEN. (2015). Water quality – sampling of fish with multi-mesh gillnets. European standard. European Committee for Standardization. Ref. No. EN 14757:2015.

Clavel, J., Pulet, N., Porcher, E., Blanchet, S., Grenouillet, G., Pavoine, S., Biton, A., Seon-Massin, N., Argillier, C., Daufresne, M., Teillac-Deschamps, P. & Julliard R. (2013). A new freshwater biodiversity indicator based on fish community assemblages. PLoS ONE 8(11): e80968. doi: 10.1371/journal.pone.0080968.

Copp, G.H. (2010).Patterns of diel activity and species richness in young and small fishes of European streams: a review of 20 years of point abundance sampling by electrofishing. Fish and Fisheries, 11:439-460.

Crow, S.K., Booker, D.J., Snelder T.H. (2013). Contrasting influence of flow regime on freshwater fishes displaying diadromous and nondiadromous life histories. Ecology of Freshwater Fish 22:82-94.

Degerman, E., Andersson, M., Petersson, E. & Sers, B. (2013). Bedömning av vattenregleringspåverkan med hjälp av elfiske. Länsstyrelsen Värmland. Publikationsnummer 2013:230, 20 p. (In Swedish)

Degerman, E., Beier, U. & Bergquist, B. (2005). Bedömning av miljötillstånd i kustvattendrag med hjälp av fisk. Fiskeriverket Informerar, 2005:1, 67 p. (In Swedish with English summary)

Degerman, E., Beier, U., Breine, J., Melcher, A., Quataert, P., Rogers, C., Roset, N. & Simoens, I. (2007). Classification and assessment of degradation in European running waters. Fisheries Management and Ecology, 14:417-426.

Degerman, E. & Lingdell, P. (1993). *pH*isces – fisk som indikator på lågt pH. Information från Sötvattenslaboratoriet, Drottningholm, 1993(3):37-54. (In Swedish)

Degerman, E., Nyberg P. & Appelberg, M. (1988). Estimating the number of species and relative abundance of fish in oligotrophic Swedish lakes using multi-mesh gillnets. - Nordic Journal of Freshwater Research, 64:91-100.

Diekmann, M., Brämick, U., Lemcke, R. & Mehner, T. (2005). Habitat-specific fishing revealed distinct indicator species in German lowland lake fish communities. Journal of Applied Ecology, 42: 901-909.

Direktoratsgruppa Vanndirektivet. (2009). Veileder 01:2009. Klassifisering av miljøtilstand i vann, 180 p. Published at www.vannportalen.no. (In Norwegian)

Eadie, J.Mc., Hurly, T.A., Montgomerie, R.D. & Teather, K.L. (1986). Lakes and rivers as islands: species-area relationships in the fish faunas of Ontario. Environmental Biology of Fishes, 15:81-89.

EFI+ CONSORTIUM. (2009). Manual for the application of the new European Fish Index - EFI+. A fish-based assessment method to assess ecological status of European running waters in support of the Water Framework Directive. June 2009, 45 p.

Emmrich, M., Brucet, S., Ritterbusch, D. & Mehner, T. (2011). Size spectra of lake fish assemblages: response along gradients of general environmental factors and intensity of lake-use. Freshwater Biology, 56:2316-2333.

Emmrich, M., Pedron, S., Brucet, S., Winfield, I.J., Jeppesen, E., Volta, P., Argillier, C., Lauridsen, T.L., Holmgren, K., Hesthagen, T. & Mehner T. (2014). Geographical patterns in the body-size structure of European lake fish communities along abiotic and biotic gradients. Journal of Biogeography, 41:2221-2233.

Emmrich, M., Winfield, I.J., Guillard, J., Rustadbakken, A., Verges, C., Volta, P., Jeppesen, E., Lauridsen, T.L., Brucet, S., Holmgren, K., Argillier, C. & Mehner T. (2012). Strong correspondence between gillnet catch per unit effort and hydroacoustically derived fish biomass in stratified lakes. Freshwater Biology, 57: 2436-2448.

Eros, T., Specziar, A. & Biro, P. (2009). Assessing fish assemblages in reed habitats of a large shallow lake – a comparison between gillnetting and electric fishing. Fisheries Research, 96:70-76.

European Commission. (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for the Community action in the field of water policy. Official Journal of the European Communities, L327:1-82.

European Commission. (2011). Guidance document on the intercalibration process 2008-2011. Guidance document No. 14. Common Implementation strategy for the Water Framework Directive (2000/60/EC), doi: 10.2779/99432, 102 p.

European Commission. (2013). Commission decision of 20 September 2013 establishing, pursuant to Directive 2000/60/EC of the European Parliament and the Council, the values of the Member State monitoring system classifications as a result of the intercalibration exercise and repealing Decision 2008/915/EC. Official Journal of the European Communities, L266:1-47.

FAME CONSORTIUM. (2004). Manual for the application of the European Fish Index - EFI. A fish-based method to assess the ecological status of European rivers in support of the Water Framework Directive. Version 1.1, January 2005, 66 p + 5 annexes.

Filipsson, O. (1994). Nya fiskbestånd genom inplanteringar eller spridning av fisk. Information från Sötvattenslaboratoriet, Drottningholm (2), 65 p. (In Swedish)

Fjälling, A., Degerman, E. & Johansson, U. (2015). Norden multimesh gill net for fish sampling in lotic environments. Lakes and Reservoirs: Research and Management, 20:182-186.

Fölster, J., Johnson R.K., Futter M.N. & Wilander, A. (2014). The Swedish monitoring of surface waters: 50 years of adaptive monitoring. Ambio, 43:3-18.

Gassner, H., Achleitner, D., Luger, M., Ritterbush, D., Schubert, M. & Volta, P. (2014). Water Framework Directive intercalibration technical report – Alpine lake fish fauna ecological assessment methods. JRC Technical Reports, Report EUR 26506 EN, 68 p., doi: 10.2788/73280.

György, A.I., Tatrai, I. & Specziar, A. (2012). Relationship between horizontal hydroacoustic stock estimates and gillnet catches of surface-oriented fish in shallow Lake Balaton (Hungary). Knowledge and Management of Aquatic Ecosystems, 405: 06. DOI: 10.1051/kmae/2012012.

Haglund, A.-L., Carlsson, T., Larson, D., Lundvall, D. & Olofsson, H. (2010). Utvärdering av biologiska bedömningsgrunder för sjöar. Erfarenheter från Dalarna. Länsstyrelsen i Dalarnas län. Rapport, 2010:16, 36 p. (In Swedish)

Hammar, J. & Filipsson, O. (1985). Ecological testfishing with the Lundgren gillnets of multiple mesh size: the Drottningholm technique modified for Newfoundland Arctic char populations. Reports from the Institute of Freshwater Research, Drottningholm, 62:12-35.

Havs- och vattenmyndigheten. (2013). Havs- och vattenmyndighetens föreskrifter om klassificering och miljökvalitetsnormer avseende ytvatten beslutade den 4 juli 2013. Havs- och vattenmyndighetens författningssamling HVMFS 2013:19, 185 p. (In Swedish)

HELCOM. (2015). Guidelines for coastal fish monitoring sampling methods of HELCOM. Last update: 10 February 2015, 25 p.

Hering, D., Borja, A., Carvalho, L. & Feld, C.K. (2013). Assessment and recovery of European water bodies: key messages from the WISER project. Hydrobiologia, 704:1-9.

Hermoso, V., Clavero, M., Blanco-Garrido, F. & Prenda, J. (2010). Assessing the ecological status in species-poor systems: a fish-based index for Mediterranean Rivers (Guadiana River, SW Spain). Ecological Indicators, 10: 1152-1161.

Holmgren, K. (2007). Fiskfaunans variation inom och mellan sjöar av olika karaktär. Fiskeriverket Informerar, 2007:1, 44 p. (In Swedish with English summary)

Holmgren, K. (2013). Importance of fish age in assessment of fish fauna status. Aqua Reports 2013:5, 66 pp. (In Swedish with English summary)

Holmgren, K. (2014). Redovisning av ”Uppdrag gällande interkalibrering av ekologisk status avseende fisk i sjöar (HaV:s dnr 2570-14). ID SLU.aqua.5.2-288, 2014-12-17, 9 p. (In Swedish)

Holmgren, K. & Appelberg, M. (2001). Effects of environmental factors on size-related growth efficiency of perch, *Perca fluviatilis*. Ecology of Freshwater Fish, 10:247-256.

Holmgren, K., Kinnerbäck, A., Olin, M., Hesthagen, T., Kelly, F., Rask, M. & Saksgård, R. (2010). Intercalibration of fish assessments of ecological status in Northern lakes – results from a pilot study. (In English with Swedish summary). Fiskeriverket Informerar, 2010:1, 37 p.

Holmgren, K., Kinnerbäck, A., Pakkasmaa, S., Bergquist, B. & Beier, U. (2007). Bedömningsgrunder för fiskfaunans status i sjöar. Fiskeriverket Informerar, 2007:3, 54 p. (In Swedish with English summary)

Jackson, L.E., Kurtz, J.C. & Fischer, W.S. (Editors). (2000). Evaluation guidance for ecological indicators. United States Environmental Protection Agency, Offfice of Research and Development, EPA/620/R/005, 109 p.

Janac, M. & Jurajda, P. (2007). A comparison of point abundance and continuous sampling by electrofishing for age-0 fish in a channelized lowland river. North American Journal of Fisheries Management, 27:1119-1125.

Jeppesen, E., Mehner, T., Winfield, I.J., Kangur, K., Sarvala, J., Gerdeaux, D., Rask, M., Malmquist, H.J., Holmgren, K., Volta, P., Romo, S., Eckmann, R., Sandström, A., Blanco, S., Kangur, A., Ragnarsson-Stabo, H., Tarvainen, M., Ventelä, A.-M., Søndergaard, M., Lauridsen, T.L. & Meerhoff, M. (2012). Impacts of climate warming on the long-term dynamics of key fish species in 24 European lakes. Hydrobiologia, 694:1-39.

Jepsen, N. & Pont, D. (editors). (2007). Intercalibration of fish-based methods to evaluate river ecological quality. Report from an EU intercalibration pilot exercise. JRC Scientific and Technical Reports, EUR 22878 EN – 2007, 194 p.

Johansson, U. (2013). Stream channelization effects on fish abundance and species composition. Master thesis. Department of physics, chemistry and biology, Linköping University. ISBN: LITH-IFM-A-EX-13/2762SE, 19 p.

Johansson, U., Gow, R., Fjälling, A., Degerman, E. & Hedenskog, M. (2012). Kartläggning av fisksamhället i Klarälven med strömöversiktsnät hösten 2011. Projektrapport Europeiska Unionen, Europeiska regionala utvecklingsfonden. 12 p. (In Swedish)

Johnson, R.K, Lindegarth, M. & Carstensen, J. (2014). Reference conditions and class boundaries: initial set of guidelines for reference conditions and class boundaries. - Deliverable 2.1-3, WATERS Report no. 2014:5. Havsmiljöinstitutet, Sweden.

Karr, J.R. (1981). Assessment of biotic integrity using fish communities. Fisheries, 6(6):21-27.

Kelly, L.F., Harrison, A.J., Allen, M., Connor, L. & Rosell, R.. (2012). Development and application of an ecological classification tool for fish in lakes in Ireland. Ecological Indicators, 18:608-619.

Kinnerbäck, A. (2015). Jämförvärden från provfisken. Ett komplement till EQR8. Aqua Reports 2013:18, 145 p. (In Swedish with English summary)

Kinnerbäck, A. (Editor). (2015). National Register of Survey test-fishing - NORS. Swedish University of Agricultural Sciences, Department of Aquatic Resources. http://www.slu.se/sjoprovfiskedatabasen [2015-05-05].

Lauridsen, T.L., Lankildehus, F., Jeppesen, E., Jørgensen, T.B. & Søndergaard, M. (2008). A comparison of methods for calculating catch per unit effort (CPUE) of gill net catches in lakes. Fisheries Research, 93: 204-211.

Leprieur, F., Beauchard, O., Blanchet, S., Oberdorff, T. & Brosse, S. (2008). Fish invasions in the world's river systems: when natural processes are blurred by human activities. PLoS Biology, 6(2):e28. Doi:10.1371/journal.pbio.0060028.

Logez, M. & Pont, D. (2011). Development of metrics based on fish body size and species traits to assess European coldwater streams. Ecological Indicators, 11:1204-1215.

Lűcke, J. (2010). En sammanställning av enkätundersökningen angående bedömningsgrunder för sjöar, vattendrag, kustvatten och hydromorfologi. Naturvårdsverket Dnr 739-8201-08Me, PM 2010-03-17, 210 p. (In Swedish)

Mehner, T., Diekmann, M., Brämick, U. & Lemcke, R. (2005). Composition of fish communities in German lakes as related to lake morphology, trophic state, shore structure and human-use intensity. Freshwater Biology, 50:70-85.

Mehner, T., Keeling, C., Emmrich, M., Holmgren, K., Argillier, C., Volta, P., Winfield, I.J. & Brucet, S. (2016). Effects of fish predation on density and size spectra of prey fish communities in lakes. Canadian Journal of Fisheries and Aquatic Sciences, 73:1-13, doi: 10.1139/cjfas-2015-0034.

Menezes, R.F., Borchsenius, F., Svenning, J.-C., Søndergaard, M., Lauridsen, T.L., Landkildehus, F. & Jeppesen, E. (2013). Variation in fish community structure, richness, and diversity in 56 Danish lakes with contrasting depth, size, and trophic state: does the method matter? Hydrobiologia, 710:47-59.

Mims, M.C., Olden, J.D. (2013). Fish assemblages respond to altered flow regimes via ecological filtering of life history strategies. Freshwater Biology, 58:50-62.

Naturvårdsverket. (2003). Undersökningstyp: biotopkartering vattendrag. Version 1: 2003-06-17. (In Swedish)

Nyberg, P., Bergstrand, E., Degerman, E. & Enderlein, O. (2001). Recruitment of pelagic fish in an unstable climate: studies in Sweden's four largest lakes. Ambio, 30:559-564.

Oberdorff, T., Pont, D., Hugueny, B. & Porcher, J.-P. (2002). Development and validation of a fish-based index for the assessment of 'river health' in France. Freshwater Biology, 47:1720-1734.

Olin, M., Holmgren, K., Rask, M., Allen, M., Connor, L., Duguid, A., Duncan, W., Harrison, A., Hesthagen, T., Kelly, F., Kinnerbäck, A., Rosell, R. & Saksgård, R. (2014). Water Framework Directive Technical Report: Northern Lake Fish fauna ecological assessment. EUR – Scientific and Technical Research series, Report EUR 26515 EN, 55 p. Doi: 10.2788/76197.

Olin, M., Malinen, T. & Ruuhijärvi, J. (2009). Gillnet catch in estimating the density and structure of fish community - comparison of gillnet and trawl samples in a eutrophic lake. Fisheries Research, 96: 88-94.

Olin, M., Rask, M., Ruuhijärvi, J. & Tammi, J. (2013). Development and evaluation of the Finnish-based lake classification method. Hydrobiologia, 713:149-166.

Palm, S., Dannewitz, J., Romakkaniemi, A., Pakarinen, T., Björkvik, E. & Östergren, J. (2014). Torneälvens lax- och öringbestånd – gemensamt svensk-finskt biologiskt underlag för bedömning av lämpliga fiskeregler under 2014. Sveriges Lantbruksuniversitet och Vilt- och Fiskeriforskningen. PM 2014-02-19, 21 p. (In Swedish)

Panfili, J., Pontual, H., Troadec, H. & Wright, P.J. (editors). (2002). Manual of fish sclerochronology. Brest, France: Ifremer-IRD coedition, 464 p.

Poikane, S., Zampoukas, N., Borja, A., Davies, S.P., van de Bund, W. & Birk, S. (2014). Intercalibration of aquatic ecological assessment methods in the European Union: lessons learned and way forward. Environmental Science & Policy, 44:237-246.

Pont, D., Hugueny, B., Beier, U., Goffaux, D., Melcher, A., Noble, R., Rogers, C., Roset, N. & Schmutz, S. (2006). Assessing river biotic condition at a continental scale: a European approach using functional metrics and fish assemblages. Journal of Applied Ecology, 43:70-80.

Pont, D., Hugueny, B. & Rogers, C. (2007). Development of a fish-based index for the assessment of river health in Europe: the European fish index. Fisheries Management and Ecology, 14:427-439.

Prchalova, M., Kubecka, J., Cech, M., Frousova, J., Drastik, V., Hohausova, E., Juza, T., Kratochvil, M., Matena, J., Peterka, J., Riha, M., Tuser, M. & Vasek, M. (2009a). The effect of depth, distance from dam and habitat on spatial distribution of fish in an artificial reservoir. Ecology of Freshwater Fish, 18:247-260.

Prchalova, M., Kubecka, J., Riha, M., Mrkvicka, T., Vasek, M., Juza, T., Kratochvil, M., Peterka, J., Drastik, V. & Krizek, J. (2009). Size selectivity of standardized multimesh gillnets in sampling coarse European species. Fisheries Research, 96:51-57.

Reyjol, Y., Hugueny, B., Pont, D., Bianco, P-G., Beier, U., Caiola, N., Casals, F., Cowx, I., Economou, A., Vigneron, T. & Virbickas, T. (2007). Patterns in species richness and endemism of European freshwater fish. Global Ecology and Biogeography, 16:65-75.

Sairanen, S., Rask, M., Stridsman, S. & Holmgren, K. (2008). Part II. A. Fish communities. Fish communities of 15 lakes in River Torne basin: aspects of lake typology and ecological status. Pp. 65-88 in: Luokkanen, E., Olofsson, P., H. Ville & B. Sundström (eds.). TRIWA II Management of an international river basin district – Torne River. The Finnish Environment 10/2008.,

Sandström, A., Asp, A., Axenrot, T., Kinnerbäck, A., Ragnarsson-Stabo, H., Holmgren, K. & P. Philipsson. Assessing the potential of remote sensing to explain spatial variation and dynamics of fish assemblages in large lakes. Submitted manuscript.

Sandström, A., Bergquist, B., Ragnarsson-Stabo, H. & Andersson, M. (2014). A test of sampling methods for fishes in an archipelago littoral zone of Lake Vänern, Sweden. Aquatic Ecosystem Health and Management, 17:357-364.

Sandström, A., Ragnarsson-Stabo, H., Axenrot, T. & Bergstrand, E. (2014). Has climate variability driven the trends and dynamics in recruitment of pelagic fish species in Swedish Lakes Vänern and Vättern in recent decades? Aquatic Ecosystem Health and Management, 17:349-356.

Schmutz, S., Bakken, T.H., Friedrich, T., Greimel, F., Harby, A., Jungwirth, M., Melcher, A., Unfer, G. & Zeiringer, B. (2015). Response of fish communities to hydrological and morphological alterations in hydropeaking rivers of Austria. River Research and Applications, 31:919-930,

Schmutz, S., Zauner, G., Eberstaller, J. & Jungwirth, M. (2001). Die "Streifenbefischungs-method": Eine method zur Quantifizirung von Fischbeständen in mittelgrosser Fliesgewässer. Österreichs Fischerei, 54: 14-27.

Schreiber, H., Filipsson, O. & Appelberg, M. (2003). Fisk och fiske i svenska insjöar 1860-1911 – en analys av fiskfaunan då och dess förändring under 1900-talet. Fiskeriverket Informerar, 2003:1, 83 p. (In Swedish)

Sers, B. (Editor). (2015). Swedish Electrofishing RegiSter – SERS. Swedish University of Agricultural Sciences (SLU), Department of Aquatic Resources. http://www.slu.se/elfiskeregistret. [2015-05-05]

Sonesten, L. (2013). Miljöövervakningen av Sveriges sjöar och vattendrag. Representativiteten av den kontrollerande miljöövervakningen. Havs- och vattenmyndighetens rapport, 2013:9. (In Swedish)

Specziár, A., Erős, T., György, A.I., Tátrai, I. & Biro, P. (2009). A comparison between the benthic Nordic gillnet and whole water column gillnet for characterizing fish assemblages in the shallow Lake Balaton. Annales de Limnologie. International Journal of Limnology, 45:171-180.

Specziár, A, Takács, P., Czeglédi, I. & Erős, T. (2012). The role of the electrofishing equipment type and the operator in assessing fish assemblages in a non-wadable lowland river. Fisheries Research, 125-126:99-107.

Spjut, D. & Degerman, E. (2015a). Fisk som indikator på hydromorfologisk påverkan. Fem delstudier med olika påverkansbedömning. SLU, Institutionen för akvatiska resurser, Dnr: SLU.aqua.2015.5.5-122, 2015-03-31, 59 p. (In Swedish)

Spjut, D. & E. Degerman. (2015b). Bedömning av morfologisk påverkan i vattendrag med elfiskedata. Aqua Reports, 2015:17, 43 p. (In Swedish with English summary)

Sutela, T., Rask, M., Vehanen, T. & Westermark, A. (2008). Comparison of electrofishing and NORDIC gillnets for sampling littoral fish in boreal lakes. Lakes & Reservoirs: Research and Management, 13:215-220.

Svenson, T., Dickson, W., Hellberg, J., Moberg, G. & Munthe, N. (1995). The Swedish liming programme. Water, Air and Soil Pollution, 85:1003-1008.

Söderberg, K., Forsberg, G. & Appelberg, M. (2004). Samordnat program för övervakning av kustfisk i Bottniska viken och Stockholm skärgård – utveckling av undersökningstyp och indikatorer. Fiskeriverket Informerar (Finfo), 2004:7, 90 p. (In Swedish with English summary)

Tammi, J., Appelberg, M., Beier, U., Hesthagen, T., Lappalainen A. & Rask, M. (2003). Fish status survey of Nordic lakes: effects of acidification, eutrophication and stocking activity on present fish species composition. Ambio, 32:98-105.

Teixeira-De Mello, F., Meerhof, M., Baattrup, A., Maigaard, T., Kristensen, P.B., Andersen, T.K., Clemente, J.M., Fosalba, C., Kristensen, E.A., Masdeu, M., Riis, T., Mazzeo, N. & Jeppesen, E. (2012). Community structure of fish in lowland streams differ substantially between subtropical and temperate climates. Hydrobiologia, 684:143-160.

Tomanova, S., Tedesco, P.A., Roset, N., Berrebi Dit Thomas, R. & Belliard, J. (2013). Systematic point sampling of fish communities in medium- and large-sized rivers: sampling procedure and effort. Fisheries Management and Ecology, 20: 533-543.

Tonn, W.M. (1990). Climate change and fish communities: a conceptual framework. Transactions of the American Fisheries Society 119:337-352.

Vadeboncoeur, Y., McIntyre, P.B. & Vander Zanden, M.J. (2011). Borders of biodiversity: life at the edge of the world's largest lakes. Bioscience, 61:526-537.

Vašek, M., Prchalova, M., Peterka, J., Ketelaars, H.A.M., Wagenvoort, A.J., Cech, M., Drastik, V., Riha, M., Juza, T., Kratochvil, M., Mrkvicka, T., Blabolil, P., Boukal, D.S., Duras, J. & Kubecka, J. (2013). The utility of predatory fish in biomanipulation of deep reservoirs. Ecological Engineering, 52:104-111.

Vehanen, T., Sutela, T. & Korhonen, H. (2010). Environmental assessment of boreal rivers using fish data - a contribution to the Water Framework Directive. Fisheries Management and Ecology, 17:165-175.

Yule, D.L., Evrard, L.M., Cachera, S., Colon, M. & Guillard, J. (2013). Comparing two fish sampling standards over time: largely congruent results but with caveats. Freshwater Biology, 58:2074-2088.

Monitoring and ecological status assessment of inland fish assemblages

This report describes the variety of fish habitats in Swedish inland waters, and their needs of different methods for monitoring and ecological status assessment. Currently used methods in different habitats are described in a background section. Separate sections summarize recent advances in monitoring and assessment, respectively. The presented state of the art may serve as guidance for further improvement of national methods and/or methods to be shared with other European countries.

WATERS is coordinated by:

Havsmiljöinstitutet
Swedish Institute for the Marine Environment

WATERS is funded by:

NATUR VÅRDS VERKET
SWEDISH ENVIRONMENTAL PROTECTION AGENCY

Swedish Agency for Marine and Water Management