ICES SGBALANST REPORT 2011

SCICOM Steering Group on Ecosystem Functions

ICES CM 2011/SSGEF:18

Ref. WGBAST
WGRECORDS
ACOM
SCICOM

Study Group on data requirements and assessment needs for Baltic Sea trout (SGBALANST)

23 March 2010
St. Petersburg, Russia

By correspondence in 2011

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Conseil International pour l'Exploration de la Mer

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Recommended format for purposes of citation:

ICES. 2011. Study Group on data requirements and assessment needs for Baltic Sea trout (SGBALANST), 23 March 2010 St. Petersburg, Russia, By correspondence in 2011. ICES CM 2011/SSGEF:18. 54 pp. https://doi.org/10.17895/ices.pub.8813

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Executive summary

The ICES Study Group on Data Requirements and Assessment Needs for Baltic Sea Trout (SGBALANST) met in St. Petersburg, Russia, 23 March 2010, and by correspondence between January 2010 and March 2011. Fifteen delegates from eight countries participated.

The study group was continued from 2007/2008, when the availability of data for an assessment was investigated, and 2009 when the status of recruitment was estimated together with information on migration. The work in 2010/2011 focussed on establishing habitat criteria for trout parr, defining a common habitat description and to give advice for future assessment of trout population status.

Previously the group has concluded that the status of the sea trout populations in the Bothnian Bay and in the Gulf of Finland is in a severe state with very low parr densities and small runs of spawners into the rivers. Also stocks in Bothnian Sea and the southeast of the Baltic Main are regionally weak. The main reason for the poor status of the northern sea trout populations appears to be the by-catch of trout post smolts in a heavy net fishery. But, also deterioration of the freshwater habitat contributes to the situation in some rivers.

In 2010/2011 a comparison of the parr habitat description at electrofishing sites was performed between countries and it was concluded that comparable data was present allowing sites to be compared with regard to habitat features (wetted width, velocity, average depth, dominating substratum, shade).

In order to estimate the amount of trout parr habitat available in different rivers often a field stream habitat survey of the whole river is performed. The group found that no joint system for this was present, but different national strategies are presented.

To enable comparisons of parr densities among sites, rivers and regions habitat criteria for sea trout of parr habitat and spawning areas was established as a part of the work 2010/2011. Also included in the habitat criteria were temperature, sediment deposition and chemical constituents of the water. From this a common sea trout parr habitat classification system (trout habitat score; THS) was constructed. It has been tested on Swedish and Danish data and is well correlated with trout parr densities. Hereby, expected parr densities may be predicted from habitat characteristics. Consequently, low densities in a good habitat may be detected, indicating an insufficient spawning population.

For the future assessment work, the group suggests four main assessment units, based on migration patterns and parr densities; Bothnian Bay, Bothnian Sea, Gulf of Finland and Baltic Main. The latter may need to be split in smaller parts in the future.

There are eight suggested potential Index Rivers, but only one has complete monitoring of parr, smolt and spawners. The other rivers will need additional sampling, e.g. the salmon index rivers Tornoinjoki and Sävarån where electrofishing is not carried out in tributaries where sea trout spawn.

Awaiting true assessment the group suggested means of estimating recruitment and trends in recruitment, recruitment status and trend rivers, based on electrofishing data.

1 Introduction

Sea trout is the sea migrating form of brown trout (*Salmo trutta*). The species is naturally distributed in North and Western Europe from the White Sea to Northern Spain, including the entire Baltic Sea area. Sea trout spawn in gravel in their home river or stream, generally in smaller rivers than salmon.

The results from the two previous reports from SGBALANST (ICES 2008, ICES 2009) may be summarized:

- Sea trout is monitored by all Baltic countries by electrofishing for parr in the natal streams, giving a good index measure of recruitment.
- Part of the monitoring of sea trout parr takes place when monitoring salmon populations. This will result in less precise estimates of sea trout recruitment, because of differences in habitat between the two species. More electrofishing sites should be established in smaller rivers and streams, e.g. tributaries of salmon rivers, to ensure sufficient coverage of trout nursery areas.
- The sea trout is only targeted directly by commercial fishing in the Main Basin.
- Information on catches is available from the larger part of the fishery with varying certainty and resolution in time. It is estimated that information on catches coming from the commercial fishery to be most precise, together with information on river catches in some of the countries.
- It is suggested that knowledge on catches in the non-commercial coastal fishery is improved, possibly by inquiries supplemented with field observations or voluntary reporting.
- Knowledge on by-catches of trout in other fisheries needs to be increased.
- The status of sea trout populations has been estimated throughout the Baltic Sea. It is evident that the status of the trout populations in the Bothnian Bay and Bothnian Sea and also in the Gulf of Finland are in a bad state with very low parr densities and small runs of spawners into the rivers. In most other parts of the Baltic the trout populations seem to be in a reasonably good state.
- The main reason for the poor status of the northern sea trout populations appears to be the by-catch of trout post smolts in a heavy net fishery targeting mainly whitefish in the Bothnian Bay and Bothnian Sea area and also pikeperch in the Gulf of Finland.
- Within a region there are often joint general trends in parr recruitment over time, but individual rivers may deviate due to local problems with the habitat, water chemistry, migration obstacles, local fishing pressure etc.
- Canalizing of many rivers has lead to profound changes in riverbed structure, removal of the larger rocks and bank vegetation. Such degraded habitat generally results in reduced physical variation and uniform depth conditions that provides less hiding possibilities for the parr and therefore carrying capacity is decreased.
- Migration patterns are known for only a few populations. While it appears that most populations make relatively short feeding migrations (distances being a few hundred kilometres), it is known that all sea areas have popu-

lations with long migration patterns, spreading into neighbouring sea areas.

- The SGBALANST group found that the status of the sea trout does justify ICES assessment, being most important in the Bothnian Bay (Subdivision 31), Bothnian Sea (Subdivision 30) and Gulf of Finland (Subdivision 32), but relevant in all parts of the Baltic Sea. Assessment should be holistic encompassing all aspects of sea trout life, i.e. access to spawning grounds, habitat and water quality, migration obstacles during seaward migration, impact from fisheries and other factors affecting survival such as natural variations in hydrologic conditions.
- The importance of establishing sea trout Index Streams in all ICES subdivisions was stressed by the group. This would allow stock-recruit parameters to be followed precisely, providing much needed information on smolt production, spawning population structure, parr densities, parr-smolt survival and influence from environmental variables.
- To facilitate the use of information from Index Rivers on a wider scale, a common classification system of habitats should be established.

The aim of the work during 2010/2011 has been focussed on comparing stream habitat descriptions in the different countries, with the goal to find a joint common denominator allowing different national systems to be comparable. This would enable comparison of the results (parr densities, smolt-production) from the index rivers with other rivers.

Further, the water quality demand of sea trout has been compiled in order to make it possible to detect rivers and streams were local conditions hamper trout parr production. Only in rivers with high habitat and water quality we can expect that recruitment will reflect the spawning stock. By compiling habitat requirements, both with respect to physical and chemical habitat, it will be possible to select suitable rivers for monitoring of population status.

2 Terms of reference

The **Study Group on Data Requirements and Assessment Needs for Baltic Sea Trout** (SGBALANST), chaired by Erik Degerman, Sweden, will meet by correspondence from January 2010 to March 2011, and will meet one day before the annual WGBAST meetings in St. Petersburg, Russia, 23 March 2010 and in 2011 during the WGBAST meeting to:

a) review habitat classification systems for sea trout used by all countries;

b) establish a common classification system of habitat quality, using both field and GIS data, to facilitate the use of data from sea trout index rivers on a wider scale;

c) identify the habitat range of sea trout with respect to depth, water quality and main substrate on the macro-habitat scale, and with respect to stream slope and width, discharge and catchment size on a metahabitat scale;

d) establish, where possible, habitat quality criteria for water temperature, oxygen, total-phosphorus, nitrogen and pH;

e) provide a provisional list of rivers to be selected as index rivers in different areas of the Baltic Sea.

SGBALANST will report by 9 March 2011 (via SSGEF) for the attention of WGBAST, ACOM, SCICOM and WGRECORDS.

3 Approach

The study group was formed in December 2007 with at least one member from each country around the Baltic Sea. The group was chaired by Stig Pedersen, Denmark, in 2007–2009, and by Erik Degerman, Sweden, in 2010/2011. Participants in the work 2010/2011 are listed in Annex 1.

The group has presented two earlier reports:

1) ICES SGBALANST Report 2007. ICES CM 2008, DFC:01, 72 p.

2) ICES SGBALANST Report 2009. ICES CM 2009, DFC:03, 101 p.

The first report focussed on gathering data to see the extent of monitoring of recruitment, spawners and smolt that occurred, and to study catch data. It was found that recruitment (electrofishing) was studied in all countries. Data on ascending spawners and especially smolt production were rare. The second report focussed on estimating the status of sea trout populations. Also a compilation of migration studies was undertaken.

During 2010/2011 the group met one day in St. Petersburg, Russia, on 23 March 2010 prior to the meeting of WGBAST. At this meeting data on habitat classification procedures in different countries was compiled. Since then the group has worked by correspondence, mainly in October 2010 – February 2011.

4 Results

4.1 Habitat requirements of sea trout parr

All aspects of sea trout life history need to be included in an assessment. Today the majority of data is on parr densities (recruitment). We use the term parr as defined by Allan & Ritter (1977); young trout that have dispersed from the redd until the smolt stage. The parr stage is sometimes subdivided according to age, where parr 0+ are young fish less than one year old etc. The habitat requirements of younger stages, i.e. with yolk sac (alevins) or with absorbed yolk sac but still residing in the redd (fry), are discussed along with spawning habitat choice of mature fish.

Recruitment of parr is a function of ascending spawners and habitat quality and quantity. It is thus essential to define boundaries for what a good parr habitat is, and what is not. The habitat includes both abiotic and biotic factors, which interact. Here focus will be on abiotic factors.

4.1.1 Physical habitat for parr and spawning

Parr summer habitat

Several studies have presented habitat use, preference and suitability for brown trout parr during summer (Fausch 1984, Heggenes 1988, Heggenes & Saltveit 1990, Shirvell & Dungey 1983, Eklöv & Greenberg 1998, Mäki-Petäys *et al*. 1997, Armstrong *et al*. 2003). Often these studies are performed as diving studies or specialised electrofishing studies focused on microhabitat of individual fish, i.e. not that type of electrofishing operations that normally are performed when estimating abundance of a trout population on a site in monitoring programmes. Most detailed studies have shown that water velocity, depth, substratum and cover are important features of the habitat's suitability for trout. Often trout chooses its microposition in the stream by optimising the sum of these factors (Fausch 1984, Heggenes 1988, 1996). Habitat selection is usually considered as a result of a trade-off between the potential net energy gain and risk (Heggenes 1996), as predation seem to be an important factor influencing habitat selection (Greenberg 1992, Bardonnet & Heland 1994, Huntingford *et al*. 1988, Eklöv *et al*. 1999).

Water velocity is measured as snout velocities, i.e. velocities directly at the individual fish position, or mean surface water velocities. In a review Heggenes *et al*. (1999) gives ranges of habitat use for daytime feeding brown trout parr in streams. For small parr (<7 cm) mean velocities were 0.1–0.5 m/s, and the corresponding values for large parr 0–0.5 m/s.

Brown trout has a narrow niche window for snout velocity and it is generally below 0.2 m/s (op. cit., see also review in Armstrong *et al*. 2003).

Water depth is often considered the most important variable defining the spatial niche for brown trout in smaller streams (Heggenes *et al*. 1999). With regard to depth the ranges of habitat use is 5–35 cm for small parr and increasing depth with size of fish for larger trout (op. cit.).

Heggenes *et al*. (1999) gives a substrate range of 16–256 mm for small parr and weakly increased particle size for larger fish. See also review in Armstrong *et al*. 2003.

Will the habitat preferences at the microhabitat level also be valid for the population of trout on an electrofishing site, i.e. at the macro-habitat level? Electrofishing data from the Swedish Electrofishing RegiSter (SERS) from sea trout streams and rivers with a catchment less than 1000 km^2 were used to demonstrate the effect of macrohabitat characteristics at the electrofishing site on occurrence and abundance of trout 0+ and >0+. The sites were electrofished during July to October (n=10 691 occasions).

The dominating **substrate** was classed into eight categories from particle size (see section 4.2.1). The abundance of parr was highest at substrates dominated by smaller particle sizes than large stones, i.e. <100 mm (Figure 1).

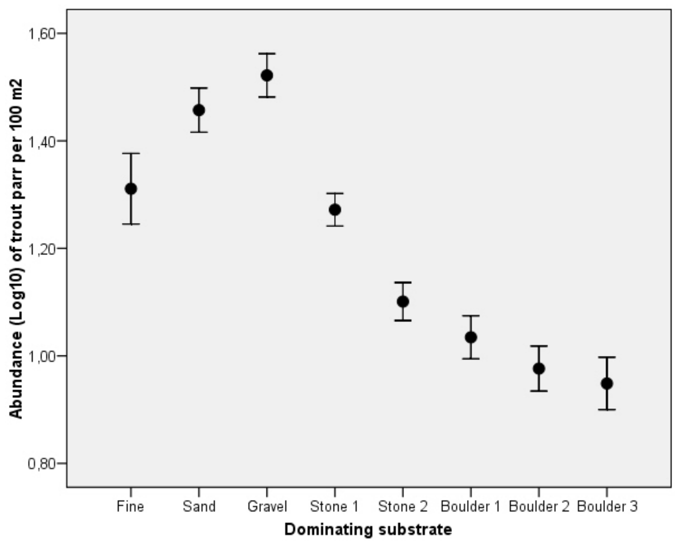


Figure 1. Abundance (log10- parr per 100 m^2) at electrofishing sites dominated by different substrate. Bars indicate 95%-confidence intervals. Data from SERS. Particle diameters are given in section 4.2.1.

The result with high abundances of parr at fine substrates, differs somewhat from studies in Norwegian rivers (Heggenes 1996), but is in agreement with results from low-gradient rivers in England (Gosselin *et al*. 2010). It is suggested that habitat use is a result of available habitat, which will differ between regions and especially between low- and high-gradient rivers. Also the presence of predators will affect habitat choice (see below).

Mean water velocity in the Swedish electrofishing procedure is only classed in three classes (slow, intermediate, fast; with classes defined as <0.2 m/s, 0.2–0.7 m/s, >0.7 m/s). Trout parr tended to be more frequent at intermediate (0.2-0.7 m/s) water velocities, but the difference between low and high velocities was small (Table 1). However, due to the large data set the differences in occurrence between velocity classes were significant (0+; Chi^2=47.6, df=2, p<0.001 and >0+; Chi^2=33.1, df=2, p<0.001). The abundance of trout, both 0+ and >0+, was highest at the slowest velocities, again with small, but significant, differences between classes (Kruskal Wallis test, Chi^2=148, df=2, p<0.001 and Chi^2=104, df=2, p<0.001).

Table 1. Occurrence (%) and average abundance (log10, individuals per 100 m^2) of trout at the three different water velocity classes.

	Occurrence (%)		Abundance (log10)	
Velocity	Trout 0+	Trout >0+	Trout 0+	Trout >0+
Slow	71.7	75.0	1.08	0.89
Intermediate	78.5	82.0	1.05	0.87
Fast	72.9	80.0	0.84	0.74

It is suggested that the average water velocity on a site, only given as three classes, does not give a good habitat description. But, velocity in combination with other habitat characteristics may be important. For example, Karlström (1977) showed the combined effect of velocity and substrate on stream position of parr of salmon and trout. In combination with dominating substrate there was an evident pattern of higher abundances of trout parr with higher velocities over fine substrates, and lower abundances with higher velocities at coarser substrate in the Swedish data set (Figure 2).

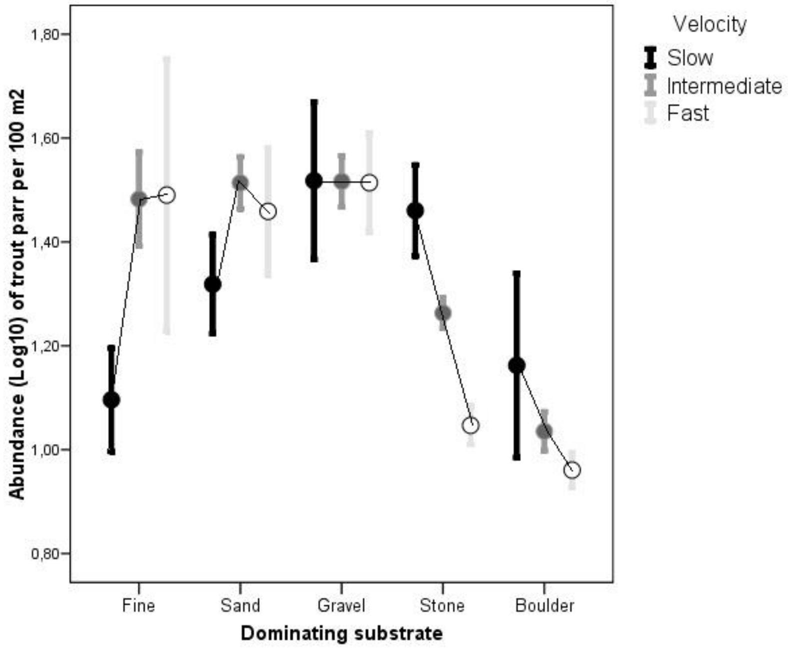


Figure 2. Average abundance (log10) of sea trout 0+ and >0+ versus dominating substrate and water velocity of fished sites. Bars indicate 95%-confidence intervals.

Average depth was normally (99.7% of occasions) below 0.7 m in the Swedish data set as fishing was done by wading. 80% of occasions had an average depth below 0.3 m. Depth was classed into four classes, 0–10, 11–20, 21–30, >30 cm. Abundance of both age-groups of parr decreased with depth, and at a depth above 30 cm trout >0+ were equally abundant as trout 0+ (Figure 3).

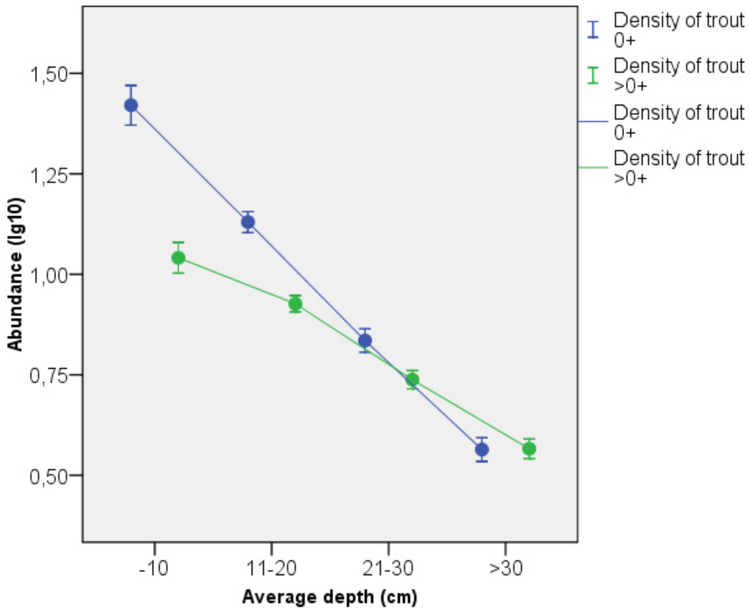


Figure 3. Average abundance (log10) of sea trout 0+ and >0+ versus average depth of fished sites. Bars indicate 95%-confidence intervals.

This was consistent with other studies. Macrohabitat use by brown trout in streams is strongly influenced by water depth. Small parr are usually found in shallow stream areas (<20–30 cm depth) (Bohlin 1977, Hermansen & Krog 1984, Nielsen 1986). With increasing size, trout parr use increasingly deeper habitat (op. cit., Kennedy & Strange 1986, Egglishaw & Shackley 1982, this study). Due to few data from deeper habitats in the present study the deepest habitat class used was >30 cm. Splitting this group to 31–40 cm and >40 showed lower abundance of trout 0+ and >0+ at >40 cm, i.e. the pattern with lowered abundance of trout with increased depth was persistent. Preference for shallow waters may be both an adaptation to low water velocities and low predation risk from other fish. In Norwegian rivers with a sparse fish fauna without predators as pike (*Esox lucius*) and burbot (*Lota lota*), it has been found that deep pools are a favourable habitat for brown trout parr (Bremset & Berg 1997), i.e. habitat preference and use is influenced by other fish species (Degerman & Sers 1993).

Slope (gradient) was estimated from maps to 0.01–10.0% at the fished sites. Increased slope results in increased water velocities. Occurrence of trout was highest at 0.4–3% slope (Figure 4).

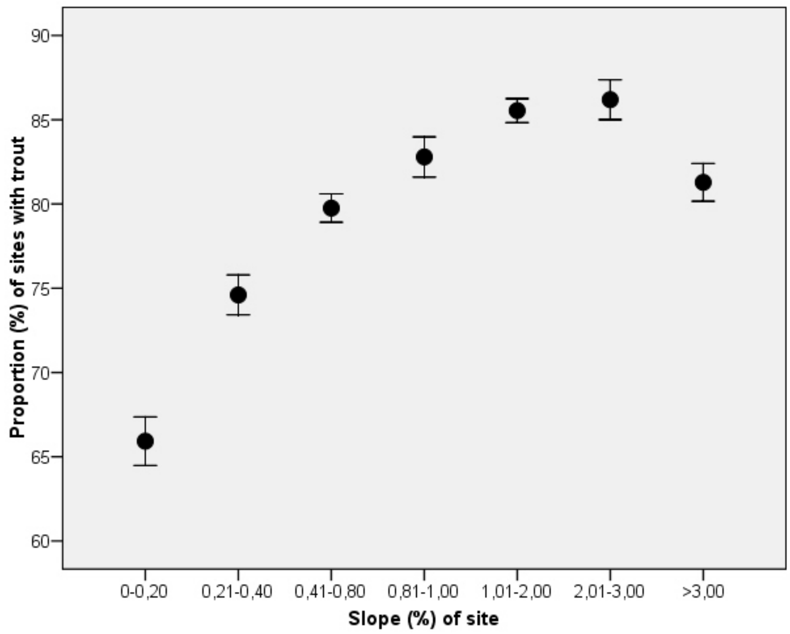


Figure 4. Average slope (%) measured from maps at electrofishing sites versus the occurrence of trout parr; average and 95%-confidence interval.

Shade (shadow provided by trees and banks) is a part of what is often labelled in-stream cover. Instream cover is often characterized as undercut banks, overhanging vegetation, broken water surface, shade and other instream structures providing sheltered standing positions for fish. Eklöv & Greenberg (1998) showed in experiments that the abundance of trout 0+ increased with cover, especially in late summer. Nielsen (1986) showed a corresponding pattern for larger trout.

Instream cover was not measured in the present study, but one of its components, shade, was. The proportion (%) of the stream surface shaded at mid day on a sunny day was estimated by the field crew in the Swedish data. Sometimes this was difficult to estimate and data is lacking from half of fishing occasions. At sites with no shade the occurrence of trout 0+ was significantly lower than at shaded sites (Figure 5). A similar pattern was present for occurrence of trout >0+.

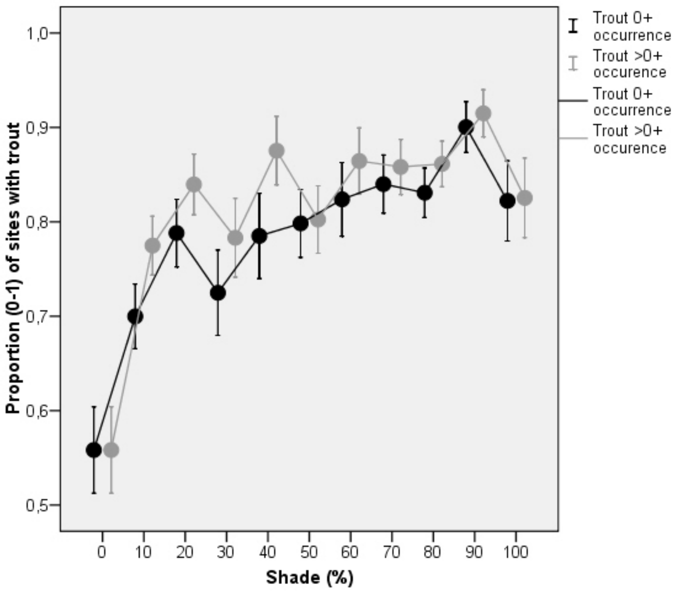


Figure 5. Proportion (0–1) of fishing occasions with trout (±95%-confidence interval) versus shade (%) of water surface. The field crew classed the shade in 10%-classes.

The quantity of **large woody debris** (LWD) is another component of instream cover. The number of pieces of LWD was counted at each site and expressed per 100 m^2. It averaged 4.3, with no LWD recorded at 26.4% fishing occasions, and more than eight pieces recorded at 12% of fishing occasions. There was a significant increase of the abundance of trout parr with increased number of LWD (Figure 6). This was in accordance with data from other waters and regions. Large woody debris is important for salmonid production (Degerman *et al*. 2004), mainly due to increased habitat diversity (Fausch & Northcote 1992). Studies have shown that artificial addition of LWD will increase salmonid density and biomass (Lehane *et al*. 2002,), as well as individual growth (Sundbaum & Näslund 1998).

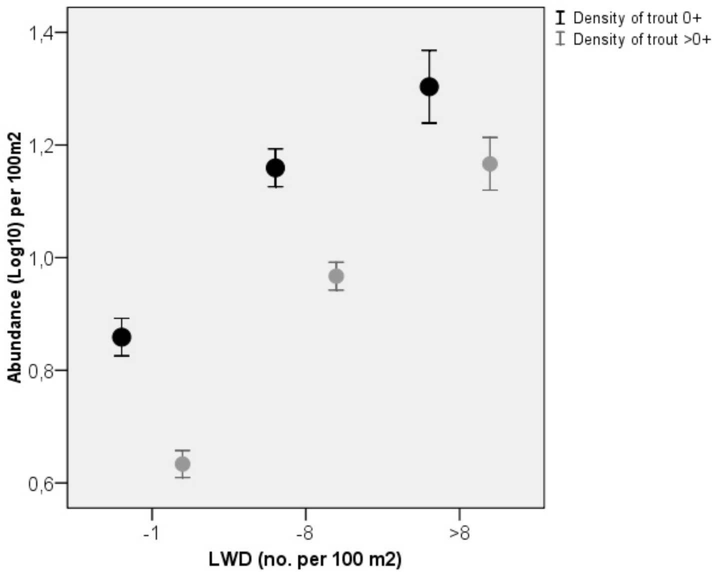


Figure 6. Abundance (log10, average and 95%-confidence interval) of trout parr versus number of pieces of Large Woody Debris (LWD) per 100 m². Bars indicate 95%-confidence intervals.

Stream wetted width is correlated to many other factors. In larger rivers trout parr tend to utilize the margin of shallow water along the shores (Lindroth 1955). This may be due both to depth and water velocity preferences. In large salmon rivers the abundance of trout parr decreases with stream width (Figure 7). Milner *et al*. (2007) has suggested 6 m as the critical stream width where salmon parr starts to be more abundant than sea trout parr, but this was done from data from rivers draining to the Atlantic Ocean, i.e. generally with higher run-off per surface area than Baltic rivers.

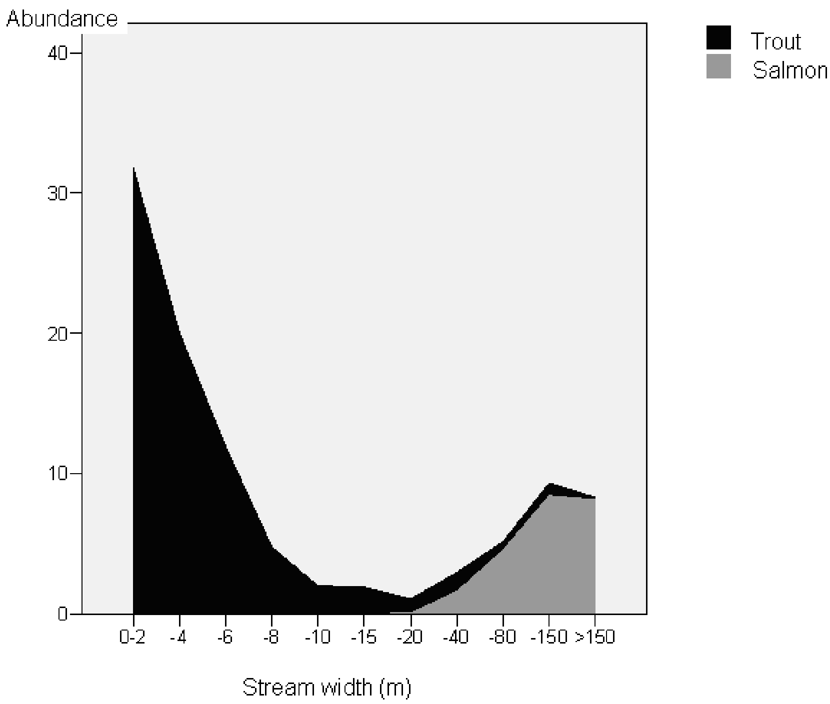


Figure 7. Median abundance (ind/100 m²) of trout and salmon parr versus stream width (m) in Swedish rivers in ICES subdivisions 30 & 31 (in 1990–2006) (ICES 2009).

Stream width is positively correlated to **catchment area**, which is positively correlated to **discharge**. The abundance of trout decreased with catchment area, but the explained variation was low (Linear regression on log-transformed data, $p<0.001$, $r^2=0.032$, $n=10691$) indicating that other factors were important for parr abundance. Also with the average discharge the abundance was weakly, but significantly negatively correlated (Linear regression on log-transformed data, $p<0.001$, $r^2=0.029$, $n=10691$).

The results above demonstrate that the average description of electrofishing sites at the macrohabitat level is valid for determining summer habitat quality for sea trout parr, and the results at the macrohabitat scale is in accordance with the pattern at the microhabitat scale.

Parr winter habitat

The cold season may be critical for salmonids in freshwater around the Baltic. The formation of an ice cover may be beneficial. Linnansaari (2009) working with salmon parr found no overall, negative effects of ice on survival and the presence of stable surface ice cover was considered beneficial for salmon parr when water temperature remained close to 0° C.

The habitat requirements for trout parr during winter are less studied, but it is evident that the spatial niche may be considerably narrower in winter than in summer (Heggenes 1996). Parr needs to find shelter from the water current and predators avoiding spending energy. Mäki-Petäys *et al*. (1997) found that trout parr in winter preferred slowly flowing stream areas, and areas with cobble-boulder substrates. Trout often sheltered among the interstitial spaces of coarse substrates, and Stickler *et al*. (2008) found substratum cover more important for salmon parr than depth, velocity or the risk of anchor-ice formation. In a review of over-wintering habitat Armstrong *et al*. (2003) concludes that at this time of the year substrate and cover becomes dominant microhabitat characteristics.

Spawning habitat

Although the spawning habitats of salmon and trout overlap, salmon tend to spawn in larger rivers and trout in the smaller tributaries (Louhi *et al*. 2008). In a stream in Pennsylvania Beard & Carline (1991) found that trout parr densities were correlated to redd densities in the reach, rather than depth or pool areas. Juvenile brown trout did not disperse widely from natal areas, hence local densities were largely a function of the availability of spawning habitat (op. cit., c.f. Nika 2011).

Physical spawning habitat criteria are narrower than the criteria for parr habitat, even compared to habitat criteria of young-of-the-year (Louhi *et al*. 2008). Adding the need for sufficient oxygenated hyporheic flows (Nika 2011) this could indicate that suitable spawning habitats may be a limiting factor for salmonid populations. Indeed, Palm *et al*. (2007) found significantly increased parr densities after increasing the number and total area of spawning areas in Hartijokki, a tributary of River Kalixälven, Bothnian Bay. Also in Denmark, there are numerous examples of increased trout parr densities in areas where spawning gravel has been added in suitable places (Gorm Rasmussen & Stig Pedersen, unpublished).

Artificial spawning redds are often placed in the transition area from pool to riffle (de Gaudemar *et al*. 2000), allowing good water intrusion into the gravel bed (Nika 2011). However, dominating groundwater intrusion in redds may be negative due to the low oxygen content (op. cit.).

Witzel and MacCrimmon (1983) reported for brown trout spawning areas water velocities in the range of 0.1–0.8 m/s, with averages around 0.4 m/s. Crisp & Carling (1989) found a lower limit of 0.15–0.2 m/s, which is in accordance with Shirvell & Dungey (1983). Louhi *et al*. (2008) gives a preferred range of 0.2–0.55 m/s.

The depth range of parr reported is 6–82 cm, with an average of 31.7 cm (Shirvell and Dungey 1983). The average corresponds well to the results of Witzel and MacCrimmon (1983). Louhi *et al*. (2008) gives a normal depth range of 15–45 cm.

There is much information on substrate with a reported preferred range of 8–128 mm (review by Armstrong *et al*. 2003), whereas Louhi *et al*. (2008) gives a narrower preferred range for trout spawning areas; 16–64 mm.

4.1.2 Temperature

Temperature is often regarded as a factor affecting the physiology and behaviour of a fish, but it is also a characteristic of its habitat, being one axis in a multidimensional niche (Magnuson *et al*. 1979). The temperature may shift between year and decades. There is some evidence that river temperatures have increased in several countries due to climate change (Caissie 2006, Elliott & Elliott 2010). As water temperature increases, it is important to obtain information on the thermal requirements of brown trout so that potential problems can be anticipated by those responsible for the conservation and sustainable management of the fisheries, and the maintenance of biodiversity in freshwater ecosystems (Elliott & Elliott 2010).

Trout are obligate poikilotherms (ectotherms) and some fish species can perceive temperature changes of <0.5°C (Murray 1971). Their gills are an effective heat exchanger, but most heat transfer (70–90%) is by conduction directly through the body wall (Elliott 1981). When the water temperature changes, thermal equilibrium must occur in the fish, but there is a time lag. In brown trout, this time lag increased with fish mass so that the body temperature of larger fish was independent of small and rapid fluctuations in temperature (Elliott 1981). It is therefore evident that small trout are much more susceptible to sudden fluctuations in water temperature than larger trout; being large is a useful buffer against sudden changes in water temperature (Elliott & Elliott 2010).

Each fish species has a characteristic thermal niche with upper and lower lethal limits. The incipient lethal temperature (ILT) is that which fishes (usually 50% of the sample) can tolerate for a long period (7 days is a usual standard), but beyond which they can survive indefinitely. The ultimate lethal temperature (ULT) is that which fishes cannot tolerate for even short time periods (10 min is the usual standard time). The latter value is sometimes called the critical thermal maximum or minimum. Critical temperatures for the survival of the different life stages of brown trout are given in Table 2 (redrawn from Elliott & Elliott 2010).

Table 2. Critical (Incipient lethal and Ultimate lethal) temperatures (°C) for different life stages of brown trout. The data in the original paper has been compiled from many references (Elliott & Elliott 2010).

Stage		Lower (°C)	Upper (°C)
Eggs		0	13
Alevins	Incipient	0-1	20-22
	Ultimate	0	22-24
Parr + smolt	Incipient	0-0.7	22-25
	Ultimate	-0.8	26-30
	Feeding	0.4-4	19-26

The lower temperature limit is for all salmonids close to 0°C, but this is under the important assumption that the water does not form ice on the sensitive gills. Eggs have the most narrow tolerance limit (Table 2) and the ultimate lower temperature (i.e. –0.8°C) is for sea trout in saltwater.

As for alevins, mortality is observed at temperatures above approx. 22°C, while the upper lethal temperature is approx. 24°C (only if exposed for a very short period) being dependant on previous adaptation to a relatively high water temperature. The parr and smolt stages are a little less sensitive compared to alevins and tolerate from a little above zero and up to about 22°C, but die within a very short time at about 26–30°C, depending on adaptation. Adaptation seems to be one of the most important factors for temperature tolerance (Alabaster & Lloyd 1980). Trout (parr) preferred (e.g. estimated in a temperature gradient) water temperature seems to be from 9–10°C and its lower and upper temperature for growth is around 4 to 19°C with an optimum at approx. 13–14°C feeding on invertebrates, and 16.6–17.4°C feeding on fish, respectively (Elliott & Elliott 2010). There is some evidence that brown trout living in very cold rivers (mean annual temperature <6.5°C) have become adapted to feed and grow at low temperatures approaching 0°C. Trout parr could in principle live in most Baltic streams provided oxygen supply is good, i.e. at least 50% oxygen saturation (see section on oxygen), but constant 100% oxygen for maximum growth and survival is required. It can tolerate lower oxygen saturation, but only for a brief period.

Fecundity and reproduction can be affected by increased temperature. Brown trout living in a heated stream with temperatures varying from about 12°C in January to about 25°C in July had poor reproductive success, with a low percentage of adults having normally maturing gonads and very few young of the year found in this part of the river, whereas brown trout living from about 1 to 14°C upstream the heated area reproduced well (Kaya 1977).

Summer drought and increased water temperature might be a severe problem and lead to increased mortality. It seems that trout prefer deep holes with water temperature below incipient level (Table 2), but with lower oxygen content compared to sites with higher oxygen but also higher water temperature (Elliott 2000). Alabaster & Lloyd 1980 recommend that for members of the genus *Salmo* which inhabit waters in sustained natural summer temperature of 20–21°C any increase in temperature could be detrimental, although temperatures may rise above these values for shorter periods.

Water will normally pass over the edge of dams in the streams. Depending on the dam size, water flow, residence time in the dam and shading, a dam will usually heat the water during daytime and downstream temperature will be higher than upstream. Small dams would often be placed in the upper parts of rivers with reduced flow in summer, and the temperature rise, particularly in the summer, could have a great effect on the downstream fish fauna (Lessard & Hayes 2003). In this study (op. cit.) there were trout stocks upstream a series of dams in temperature ranges from ca. 13°C to approx. 23°C, but with much greater densities below 20°C. At 13°C trout density was approx. 150 times higher than at 20°C and 400 times larger than at 23°C. An average summer temperature increase from 16.8°C to 19.5°C reduced densities of trout by 61%.

4.1.3 Oxygen

Sensitivity of fish to low concentration of dissolved oxygen (DO) differs between species, life stages (eggs, larvae, and older stages), and between the different life processes: feeding, growth and reproduction, which in turn may depend on swimming ability, and behaviour which may also be influenced by DO (Alabaster & Lloyd 1980).

There is a considerable volume of laboratory data on the effects of DO on fish life processes (e.g. respiration rate as function of fish size, temperature and feeding level, standard metabolism and feeding metabolism, i.e. SDA). Much of it is incomplete in terms of the distribution within wild fish populations at given physiological and behavioural states, and difficult to interpret in terms of ecological significance.

Young salmonids are most sensitive to low levels of oxygen around the time of hatching, and high mortalities occurred by a sudden reduction of DO to 2–3 mg/l for six days (Alabaster & Lloyd 1980). Older salmonids are less sensitive because of a smaller relative metabolism (O_2/g fish weight). The lethal levels of DO for salmonid species ranges from about 0.95 to 3.4 mg/l depending on temperature (i.e. within a normal temperature range) (op.cit.).

Super-saturation of DO mostly resulting from phytoplankton activity is only lethal when gas-bubble "disease" is caused by the sum of the partial pressures of all dissolved atmospheric gases being greatly in excess of the hydrostatic pressure, or when accompanied by high pH. This phenomenon should normally not be important in brown trout streams but only downstream eutrophic lakes during summer and high temperature combined with increased pH (i.e. increased phytoplankton production).

Levels of DO which might affect fertilization of eggs appear to be largely unknown for salmonids (Alabaster & Lloyd 1980). But with salmonids any reduction of DO from the air saturation value (ASV) or supersaturation can retard development, end embryonic growth, reduce size at time of hatching, or delay hatching. Most eggs will hatch more or less successfully at between 2 and 3 mg O_2/l to produce relatively small and underdeveloped larvae that are viable and not deformed (op.cit.). Neither reduction in DO to about 5 mg/l nor moderately wide diurnal fluctuations around this level has much effect on growth of salmonid alevins; at about 3 mg/l there might be a slight reduction in growth and the size of the fry without yolk sac is reduced about 25%. A 'carry over' effect from hypoxia on embryos resulting in reduced swimming performance in fry was reported by Roussel (2007).

Level of DO might affect growth rate of salmonids. Pedersen (1987) found at 15°C that rainbow trout had reduced feeding rate and growth rate (G %) at oxygen saturation below 70% and no growth rate below about 20% DO saturation; it is expected that the same may occur for brown trout and could be a "problem" during summer with relatively high water temperature accompanied with daily varying DO content.

Some salmonids (rainbow trout *Oncorhynchus mykiss*) can acclimate to low DO, the length of time required depends on temperature (op.cit.).

Swimming continues more or less at near-lethal level of DO, but maximum sustainable swimming speeds of salmonids decline with any reduction of DO below saturation (Alabaster & Lloyd 1980).

For the data available the annual 50-percentile and 5-percentile of DO for salmonids, including brown trout, should be 9 mg O_2/l and 5 mg O_2/l (Alabaster & Lloyd 1980), but these values should only be used for general guidance, because there are circumstances where more considerations should be given to the seasonal/daily distribution of DO, increased temperatures and other stressors.

4.1.4 Nutrients and productivity

Production in fresh water is basically limited by the availability of inorganic nutrients. In aquatic freshwater ecosystems influenced by drainage from cultivated land, phosphorus is usually the production-limiting nutrient.

Phosphorous as such does not reach levels in natural waters where it directly affects fish, instead when the resulting blooms of algae and weed die, the process of decomposition strips oxygen from the river water. Large scale inventories in southern Sweden showed that trout presence was explained by water oxygen levels and medium-sized substrata, whereas the concentration of total-phosphorus was not significantly correlated to trout presence (Eklöv *et al*. 1999).

Trout populations in streams are in general regulated primarily by density dependent mechanisms reflecting the carrying capacity of the stream, ultimately determined by availability of habitats and food (Milner *et al*. 2003, Armstrong *et al*. 2003). Density dependant mechanisms may regulate populations in streams with higher production, i.e. high initial number of egg/fry, but not in oligotrophic streams where densities may be too low for them to operate (Almodovar *et al*. 2006).

It is in general difficult to differentiate between the effects on trout production from temperature and from chemical nutrients regulating primary production (and indirectly secondary production). Trout populations are also dependant on habitat quality. Normally trout densities are measured without concomitant measures of nutrient levels of the water. Relations between densities and habitat quality are much more frequently reported while studies on trout production and stream productivity as an effect from high nutrient load are few.

Almodovar *et al*. (2006) found a positive relationship in Spanish streams from chemical features associated with high water productivity and trout production, but not between water productivity and standing crop or P/B ratio. They (op.cit.) also analyzed published levels of trout production on a European level and found a positive correlation between production and alkalinity.

In North America increased primary production has been observed in several studies where sections of rivers or entire rivers have been fertilized and in some studies also an accompanying growth in salmonids (Johnston *et al*. 1990, Manley 2005, Slaney *et al*. 1986). Experiments with addition of sucrose (maintained sucrose concentration in the stream water of 4 mg/l) more than doubled the production of a trout population as an effect of increased invertebrate production (Warren *et al*. 1964).

Gislason *et al*. (1998) found a positive relation between salmon (*Salmo salar*) catch (as a proxy for productivity) and the productivity of a river (especially positive if large lake areas are inserted) and no effect from catchment area if the river originates in barren land.

In contrast to Almodovar *et al*. (op. cit.), LeCren (1969) found no obvious relation between production of trout and alkalinity in 10 English streams. However, he suggests that this may be due to other causes such as elevation and effects from pollution.

In nutrient rich high alkaline chalk streams in England Mann *et al*. (1989) found no evidence of food being a limiting factor in the populations studied. Trout growth in these streams was rapid and production high. Elliott (1994) concludes growth in general to be controlled by temperature and that trout in general are eating at maximum level; and when growth is below calculated model values it is likely to be due to shortage of food (i.e. low productivity in streams).

4.1.5 Nitrite and total ammonia

Nitrogen is often measured as total-nitrogen in water. It consists of organic bound nitrogen and inorganic nitrogen. Inorganic nitrogen may exist as nitrogen gas (N2), as ammonia (NH3), ammonium (NH4+), nitrite (NO2-) or nitrate (NO3-). Nitrites and nitrates are produced when bacteria break down nitrogen-rich compounds first into nitrite, and then into nitrate. Plants prefers ammonium and nitrate, which stimulate the growth of plankton and higher vegetation. This may increase the fish population. However, if algae and other plants grow too wildly, oxygen levels will be reduced and fish will die.

Nitrites are actively transported across the gills and readily oxidize hemoglobin to form methemoglobin. Methemoglobinemia results in hypoxia, severe enough to cause sudden death but often the fish will live until they exert themselves. The term "brown blood disease" comes from the appearance of the blood that has high levels of methemoglobin (which is brown).

Nitrate-nitrogen levels below 90 mg/l and nitrite levels below 0.5 mg/l seem to have no effect on warm-water fish (US EPA 1986), but salmon and other cold-water fish are more sensitive. Lewis & Morris (1986) in a review gives an LC_{50} (lethal concentration when 50% of the population dies) of 0.15–12.6 mg/l NO_2^- -N for salmonid fish, depending on fish size and especially the chloride concentration. Negative effects on fish starts earlier (e.g. Smith & Williams 1974) and US EPA (1986) recommends a nitrite maximum for salmon of 0.06 mg/l (60 µg/l) (op. cit.).

The term total ammonia normally refers to two chemical species which are in equilibrium in water (NH_3 and NH_4^+). They are usually measured together. Total ammonia levels greater than approximately 0.1 mg/l usually indicate polluted waters. The toxicity of ammonia is primarily attributable to the un-ionized form (NH_3). Toxicity, expressed as total ammonia in the environment, increases with water pH, because ammonia enters organisms as NH_3 and the proportion of NH_3 increases with water pH (Randall & Tsui 2002). At a pH of 6.5 US EPA (1985) reports lethal concentrations (LC_{50}) of four days exposure of salmon parr to 0.73 mg/l, increasing to 0.17 mg/l at a pH of 8.5. When levels reach 0.06 mg/l, fish can suffer gill damage (Knepp & Arkin 1973). Also, ammonia is much more toxic to fish and aquatic life when water contains very little dissolved oxygen and carbon dioxide.

Nitrate is less toxic. A maximum level of 2 mg NO_3-N/l would be appropriate for protecting the most sensitive freshwater species (Camargo *et al*. 2005, Camargo & Alonso 2006).

It is recommended that both nitrate and total ammonia should be below 0.06 mg/l in short term exposure (days) to ensure salmonid production. In long term exposure (months) levels should be lower.

4.1.6 Suspended solids, turbidity and siltation

Suspended solids

Suspended solids produce two main ecological effects in streams that can affect fish and other aquatic organisms; increased turbidity of the stream water, and increased siltation of stream beds. Turbidity is reduced light transmission through water due to absorbance and scattering by solid particles in suspension. During low flow periods most streams and rivers are quite clear, but may become turbid during storm events or snow melt. There is a good correlation between total suspended solids (TSS) and turbidity. But, turbidity also depends on particle size, form and colour (Alabaster & Lloyd 1980, Lloyd *et al*. 1987). Agricultural areas, areas with clear-cutting of riparian forest, areas prone to bank erosion as well as urbanized areas contribute large amounts of fine particles. Headwaters are generally less turbid than main stems. An interesting effect of temperature on water is to alter its viscosity, and this causes silt to sink twice as fast at 23°C as it does at 0°C. Therefore, warm water carries less silt than cold water.

Suspended sediment can be measured directly as the dry weight of Total Suspended Solids in a volume of water (TSS in mg/l, ppm) or indirectly as the extent of light scattering reported by a turbidity meter. The most widely used measurement units for turbidity are FTU (Formazin Turbidity Unit), FNU (Formazin Nephelometric Units) or Nephelometric Turbidity Units (NTU). These units are approximately comparable, i.e. 1 FTU ≈ 1 FNU ≈ 1 NTU (Lloyd *et al*. 1987). Increased levels of TSS (and turbidity) over background rates can injure fish gills and limit feeding success. But, salmonid parr can survive high concentrations of suspended sediment for considerable periods. Acute lethal effects generally occur only if concentrations exceed 20 000 mg/l (Sorenson *et al*. 1977). The negative effects of turbidity increase with exposure time (Newcombe & MacDonald 1991). In a literature review Rivinoja & Larsson (2001) concluded that most fish species, including salmonids, can survive and feed at least a couple of weeks in turbid water. It is probable that the most deleterious effect indicated by turbidity is the clogging of bottom interstices by fine sediment. This is discussed below.

Sub-lethal effects of turbidity on emerged salmonids may be divided into physiological, behavioural and resistance to disease (Alabaster & Lloyd 1980). Fish subjected to continuous clay turbidity (>25 NTU) grew less than those living in clear water (Sigler *et al*. 1984). This may be an effect of gill clogging (Servizi & Martens 1992) or that visual feeding is impaired (Gregory & Northcote 1993). If fish in natural streams are subjected to high turbidity soon after emergence, substantial emigration might occur (Sigler *et al*. 1984). Short-term increases in TSS levels significantly influenced the behavior of juvenile Atlantic salmon in fall and winter. The initial introduction of sediment (20 mg/l, or ≈15 NTU) increased foraging activity, which subsequently declined at sediment levels greater than 180 mg/l (Robertsson *et al*. 2007). An avoidance response was noted at sediment levels ranging from 60 to 180 mg/L (≈22–42 NTU). Juvenile coho salmon (*Oncorhynchus kisutch*) were subjected to experimentally elevated concentrations of suspended sediment (Bisson & Bilby 1982). They exhibited significant avoidance when turbidity exceeded a threshold of >70 NTU. Berg (1982) found that the effectiveness of salmonid parr in obtaining food was reduced at 20 NTU.

Turbidity may impair salmonid production also through effects on primary and secondary production. An increase of 5 NTU in turbidity in a clear stream 0.5 meter deep may reduce primary production by 3–13% (Lloyd *et al*. 1987).

In a Swedish study of abundance of 0+ brown trout parr, a significantly lowered abundance was noted in streams with a turbidity above 1 as compared to streams with lower turbidity (average parr densities 16,0± 3,6 per 100 m^2 at < 1 FNU; 3,6±1,6 at >1 FNU; ANOVA $F_{1,54}$=8,15, p=0,006) (Söderberg *et al*. 2008). The ultimate factor for lowered abundance is not known, but sediment deposition in spawning areas may be the cause. In this study turbidity was comparable low; 0.3–8 FNU.

Turbidity is not a reliable measure in all situations for determining the effects of suspended solids, but is widely used. It is recommended in some states of the United States that salmonid waters should not exceed 10 NTU (Bash *et al*. 2001). A review of studies conducted in Alaska and elsewhere indicated that water quality standards allowing maximum increases of 5 NTU units above ambient turbidity in clear coldwater habitats provide relatively high protection for salmonid fish resources in Alaska (Lloyd *et al*. 1987). However, Swedish results indicate that negative effects on trout abundance can be found at lower turbidity, albeit if it was turbidity or correlated factors responsible for the negative impact is not clear (Söderberg *et al*. 2008).

Siltation

Finer sediments (< 2 mm; sands, silts, and clays) are flushed downstream and may be deposited on top of existing bottom material (sand) or may be infiltrated into gravel interstices (sand, silt, clay) (Lisle 1989). The interstitial spaces among the large streambed components normally holds clear flowing water, usually highly saturated with dissolved oxygen. Fine sediments may clog the interstitial space and prevent salmonid eggs from receiving oxygen and inhibit removal of waste products with water flow (Everest *et al*. 1987), or they may form a film around the eggs deposited in the gravel (Greig *et al*. 2005).

There is a negative correlation between the proportion (%, in weight) of fine particles and egg/fry survival (Everest *et al*. 1987, Nika 2011). O'Connor & Andrew (1998) found 100% mortality of Atlantic salmon eggs at 15% fine sediment in the bottom substrate. Bryce *et al*. (2008) showed that even an increase of fines (<0.85 mm) from 0% to 5% resulted in increased mortality of Chinook and Coho salmon embryo. At 10% fines the mortality as compared to references was elevated by 49–61.5%. Louhi *et al*. (2008) have reviewed the literature and concluded that as low as 1.5% of very fine clay and silt (<0.125 mm) restrict oxygen uptake of embryos, apparently because the clay particles form a film around the eggs (Greig *et al*. 2005).

In an experimental study Olsson & Persson (1988) found a significant decrease in hatching of brown trout ova when the proportion of sand in the substrate was 20% or higher. Nielsen (2003) found mortality to be elevated when the proportion of sand was above 14%, and that survival was merely a function of burial depth beneath the substrate surface. Instead of a survival percentage he found a survival depth, with 100% mortality in all eggs buried deeper than a certain level. Sand deposited on top of the bottom substrate may be negative to emergence of alevins to the surface (Kondolf 2000). However, Crisp (1993) found that alevins of sea trout and Atlantic salmon may emerge through an 8 cm sand layer.

Fine sediment may also affect salmonid parr growth and survival (Suttle *et al*. 2004). This was due to a shift in invertebrates toward burrowing taxa unavailable as prey and with increased parr activity at higher levels of fine sediment.

Intrusion of fine sediment into spawning areas will have negative effects of embryo and parr survival. This effect varies with groundwater flux, substrate coarseness, and ambient water quality. Large-scale surveys of fine sediment in trout spawning grounds in England has lead Milan *et al*. (2000) to set a target loading of 14% of fine sediment (<1 mm) in the substratum of healthy streams. This is in accordance with the value of 15% given by O'Connor & Andrew (1998) for Atlantic salmon eggs, but higher than results reported of Bryce *et al*. (2008). It is suggested that 5% of fines may be a reasonable threshold (c.f. Nielsen 1995); although the results of Bryce *et al*. (2008) indicate that no definitive thresholds exist. It should be noted that intrusion of fine silt and clay is likely to prove harmful at much lower proportions (Louhi *et al*. 2008, Greig *et al*. 2007).

4.1.7 pH and aluminium

Acidification due to deposition of air-borne pollutants has been a severe threat to salmon and sea trout stocks in Scandinavia, the British Isles and parts of Northern America. Acidification of boreal watercourses due to acid deposition of long-transported air pollutants was discovered early in the 20th century (Dahl 1927). Acidification results in both chronically and episodically acidified rivers, the latter especially during snow-melt. Today, water quality is slowly improving in affected rivers due to reduced acid deposition. Awaiting lowered acid deposition, liming of acidified water with fine-grained lime-stone has proven an efficient method to sustain fish production (Henrikson & Brodin 1995). In the Baltic region extensive liming operations are carried out to counter-act the acidification process in certain areas of Sweden, especially in rivers flowing to ICES subdivisions 25, 27 and 30.

Naturally acid water is produced by humic compounds leaching from organic soils. Humic river waters are generally brownish and slightly acid (pH around 6-6.5). However, in the middle and northern coast of the Bothnian Sea and on the southern and middle coast of the Bothnian Bay there are abundantly sulphide-bearing clay soils in the lower parts of the river catchments. They have been developed from sediments deposited during the Litorina period (5000 to 1000 B.C.) of the Baltic Sea and contain metal sulphides formed and accumulated under reduced conditions. As a result of land elevation, drainage or dry summers the groundwater table may go down, and sulphide is exposed to air, leading to formation of sulphuric acid. Many rivers and watercourses in western Finland have experienced fish deaths during the last decades caused by occasional peaks of acidity (pH <5). In addition of the acidity, the lethal effect has been attributed to the high concentration of dissolved Fe, Al and Mn. Fish kills occur in river waters especially during runoff peaks during autumn rains and in spring when the quantity of water leaching the soil profile is highest (Hartikainen & Yli-Halla 1986). Also other potentially toxic metals such as cadmium (Cd), nickel (Ni) and zinc (Zn) have been found in high concentrations in rivers discharging from acid sulphate soils (Roos & Åström 2006). However, dissolved humic material has been found to reduce the acute toxicity of iron and aluminium for juvenile brown trout and grayling in acid water (Vuorinen *et al*. 1998).

Acidification of water is a reduction of pH, which leads to a mobilization of iron, manganese and aluminium from the soil. Negative impact on fish and other animals are due to all these factors (Geertz-Hansen *et al*. 1986; Geertz-Hansen & Rasmussen 1994; Nyberg *et al*. 1995, Gensemer & Playle 1999). Low pH impedes osmo-regulation, whereas dissolved inorganic (monomeric) aluminium (Al_i) accumulates on gills and impedes both osmo-regulation and oxygen exchange (op. cit.; Brown & Sandler 1989). Toxicity is normally attributed to Al_i and sometimes iron or manganese, unless the water is very acid and the direct effect of hydrogen ions dominates (Gensemer and Playle, 1999; Rosseland & Staurnes 1994). At intermediate pH-levels (approx. 5.4–6) pH and metal ions interact and represent a combined pressure on fish health. Naturally the effects on fish depend on fish life history, size, species, exposure time, recovery time etc. This short review focuses on lethal levels of pH, Al_i and iron.

The toxicity of aluminium decreases with increased amount of humic substances (Geertz-Hansen *et al.*1984; Laudon *et al.* 2005) and calcium (Brown 1982). Generally the negative impact of low pH and elevated aluminium is most pronounced for hatching roe, yolk-sac fry and for smolt, while parr are more tolerant (Rosseland & Staurnes 1994; Gensemer & Playle 1999; Kroglund *et al.* 2008). Smolts exposed to acidic water displays sub-lethal ion regulatory stress both in fresh and seawater, with mortalities in seawater (Magee *et al.* 2001).

In aquaria experiments Geertz-Hansen *et al.* (1984) measured the survival and plasma chloride (Cl^-) of 12–14 cm brown trout, pH = 5.5 and temperature = 6.5°C, at inorganic aluminium concentrations from zero to 5.5 mg/l. After three days about 65% of the trout had survived at 0.18 mg/l, but only 5% survived at about 0.75 mg/l. At 1.15 mg/l no trout survived after three days. The plasma chloride content, which is a measure of ability of osmoregulation and stress (lowered chloride content), was reduced similarly to about 89% and about 70% compared to the level of zero aluminium concentration. From a pH at about 6.5 no direct toxic effect from aluminium was recorded, but if ferro-iron (Fe2+) was added combined effects (i.e. increased mortality) between the two minerals was observed. During the experiments it was seen that coagulated mucus accumulated in the gill filaments and thus impaired the respiration and osmoregulation in accordance with the chlorine results. It was recommended that the concentration of inorganic aluminium in general should never be above about 0.1 mg/l in streams for permanent trout stocks (i.e. Danish streams).

Water quality guidelines for salmonid fish have been lacking, but Kroglund *et al.* (2008) have compiled data for Atlantic salmon (*Salmo salar*). They found a high survival rate of salmon parr at pH >5.6 and Al_i <45 µg/l. For smolt the corresponding values were pH >5.8 and Al_i <40 µg/l. But, these are short-term survival estimates. Smolts were tested in a subsequent seawater challenge test showing negative effects also at levels of pH and Al_i that were not directly lethal. Only when pH in freshwater was >6.5 and Ali<5µg/l no smolt mortality was observed in this test (op. cit.). This lead Kroglund *et al.* (2008) to state that salmon populations in rivers having pH >6.2 and Al_i <3µg/l were unaffected by acidification. For the Swedish liming programme also pH >6,2 has been set as a critical limit for salmon.

Atlantic salmon is in general more sensitive to acidification than sea trout, e.g. for hatching roe and yolk-sac fry (Johansson *et al.* 1977; Norrgren & Degerman 1993, Poleo *et al.* 1997). At pH below 5.4–5.5 a direct effect of pH on Atlantic salmon (*Salmo salar*) roe/fry is present, whereas for sea trout the corresponding value is <5 (Johansson *et al.* 1977; Norrgren & Degerman 1993). Serrano *et al.* (2008) suggest a critical chemical threshold of pH 4.8–5.4 for trout parr survival. Bridcut *et al.* (2004) found a higher correlation between trout parr and ANC (acid neutralising capacity) than with pH. At an ANC level of 0.039 meq/l there was a 50% probability of brown trout occurrence in Scottish streams. This would correspond to a pH-values of circa 5.5–5.6. Production and abundance of trout parr should be affected at even higher pH-values.

Electrofishing data from central Sweden showed significantly lowered abundances of trout parr at lowest recorded pH during the year of 5.8 (Åslund & Degerman 2007).

Field tests have shown that trout parr can withstand Al_i <30 µg/l (Cecilia Andrén, Stockholm University, pers. comm.). Acceptable water quality over a 7-day period for 11-cm trout yearlings was obtained in water having <60 g Ali/L (Andrén *et al*. 2006). At higher Al_i the fish is stressed and mortality starts.

These data indicates higher tolerable Al_i levels for trout than those for salmon (Kroglund *et al*. 2008). But, for the most sensitive stage, smolts, adequate data are lacking. One difference between salmon and sea trout regarding smolt sensitivity to acidification is related to how they use seawater. Salmon must reach full strength seawater fast. Sea trout can stay close to the estuary and successively adjust. If seawater tolerance is compromised, salmon is more likely to suffer than sea trout. Without data for the sensitive smolt stage it is suggested that a conservative value of pH 5.8 should be used as an indicator of unaffected for sea trout populations.

The occurrence of acid river water due to air-borne pollutants or natural soil acidity poses risks to maintenance of the natural sea trout stocks. This kind of risk could best be reduced by decreasing air pollution and by developing and introducing environment-friendly agriculture, e.g. avoiding of deep drainage of potentially acid sulphate soils. Climate change is predicted to increase river flow in general and winter discharge in particular, and therefore the acidity problems in affected rivers may increase in a future climate (Saarinen *et al*. 2010).

4.1.8 Iron

In addition to the mining of Fe enriched ores, acidification, intensified forestry, peat production and agricultural draining have increased the load of iron in many river ecosystems (Vuori 1995). Low-lying areas with fluvial deposits or areas with lignite mining (brown coal) contain pyrite (FeS_2) or siderite ($FeCO_3$), but as long as these iron-compounds remain in the soil without access to air they remain chemical unchanged. When exposed to the atmosphere on the surface of a lignite strip mine, by drainage of peat bogs, or by other measures that lower the groundwater level, the pyrite or siderite is oxidised, causing the formation of sulphur or carbonic acid and iron salts, predominately ferric sulphate or ferric carbonate.

The buffering capacity of the streams will control the time taken for the soluble iron (Fe^{2+} and/or Fe^{3+}) to be transformed into ferric hydroxide (ochre), which is insoluble and thus precipitates. The potential detrimental effects of iron on the fish populations in streams and trout ponds were recognized as early as in the 1930s (Geertz-Hansen & Rasmussen 1994). The combination of acid water and iron on the development of trout eggs and larvae has the following effects; soluble iron (Fe^{2+}) might be precipitated on and between the stones of the gravel and/or upon the low alkaline surfaces of the eggs and the gill epithelium of developing sac-fry larvae and fry and parr trout (Figure 8). Also, there might be a direct toxic effect of the iron in combination with lowered pH on the eggs larvae, fry and parr (op. cit.).

Different stocking and survival experiments using brown trout (12–14 cm) in many different Danish streams with varying pH and ferro-iron concentrations gave the following recommendations:

a) a) In trout streams with pH less than 6 the ferro-iron concentration should be less than 0.5 mg/l;

b) b) for pH between 6 and 6.5 the ferro-iron concentration should be less than 1.0 mg/l;

c) c) for pH above 6.5 the concentration should be less than 1.5 mg/l (Geertz-Hansen *et al.* 1984 & Geertz-Hansen *et al.* 1986) to secure brown trout populations of older fry and parr.

The limit values were dependent of the water temperature, so that higher levels of ferro-iron could be tolerated during summer compared to winter with cold water.

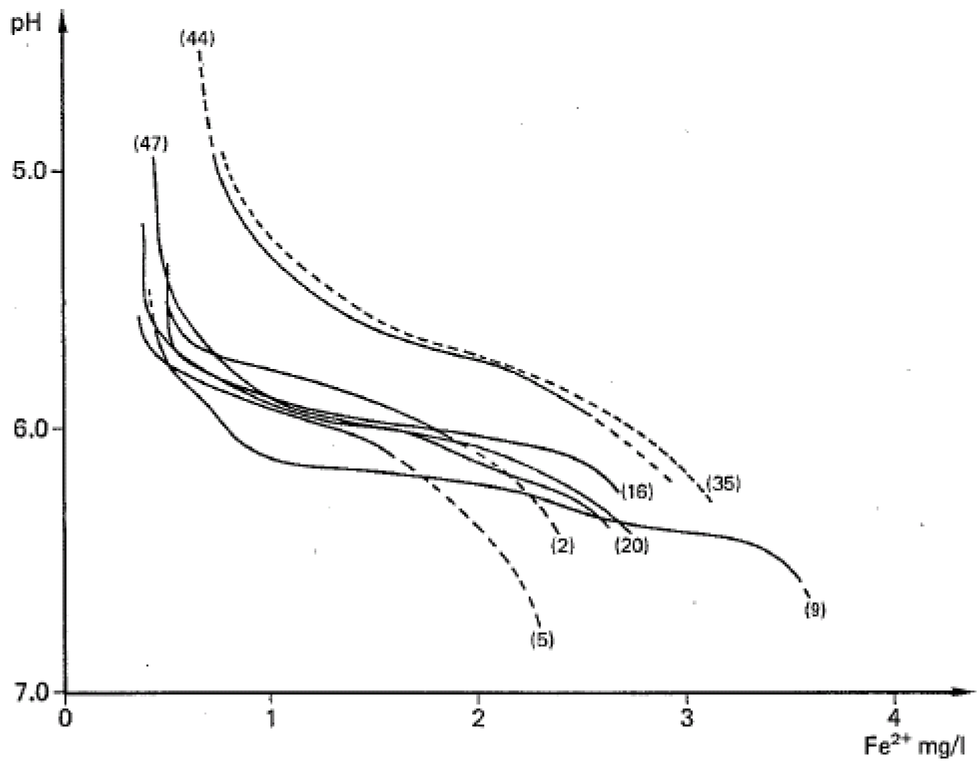


Figure 8. Relationship between Fe^{2+} and pH of more than 80% survival of brown trout (i.e. below curve) after one week in cages; observations of less than 20% survivals are above curve. Numbers in parenthesis are week of the year. Redrawn from Geertz-Hansen *et al.* 1984.

Eyed brown trout eggs were transported to some of the same experimental sites and were placed in Vibert boxes and buried about 10 cm down in the gravel of an artificial made spawning ground. Temperature recordings made it possible to calculate the date when all the eggs would have hatched under normal circumstances and after hatching the number of dead and live eggs and larvae were counted (Geertz-Hansen & Rasmussen 1994). The eggs were incubated for about 5–6 weeks. The pH varied from 5.37 to 7.41 but the effect from pH was not statistical significant (op. cit.). For ferro-iron concentrations less than 0.65 mg/l there was no statistical significant difference in larval survival, but the relationship between % larval maximal survival and Fe^{2+} (>0.65 mg/l) gives the following relationship:

$$\text{Survival (\%)} = 42.4 (\pm 18.2) - 18.95 (\pm 14.8) \times Fe^{2+} \text{ (mg/l)}, r = -0.27, p<0.01$$

Eyed eggs (about 150 eggs in each dish) were placed in petri dishes (32 boxes) with holes and placed in the open water in the same period (recovered a little earlier) as the Vibert boxes. The pH varied from 5.93 to 7.05 (op. cit.).The eggs were incubated for about 4 weeks. The results showed increased mortality with ferro-iron concentrations (Table 3).

Table 3. Egg hatching and larval survival in relation to iron concentrations. Data from Geertz-Hansen & Rasmussen 1994.

Fe^{2+} (mg/l)	Egg hatching % (±95% CL)	Maximal larval survival % (±95% CL)	Number of Petri-dishes
$Fe^{2+} \leq 1.0$	97.3% ± 1.4%	75.3% ±12.8%	13
$1.0 < Fe^{2+} \leq 2.0$	58.2% ± 20.6%	34.2% ± 4.3%	9
$2.0 < Fe^{2+}$	43.4% ± 25.1	10.9% ± 6.7%	10

It was recommended that in streams with normal egg and larval development of salmonids, the content of Fe^{2+} should not increase above 0.5 mg/l (op.cit., Geertz-Hansen & Mortensen 1983).

Precipitated iron (ochre) also has a heavy effect on invertebrate production. In streams with high levels of ochre the insect fauna is much reduced; parr and larger trout can survive but they are few in number (probably because of lack of food and therefore have larger territories) but in good condition (Geertz-Hansen *et al*. 1984).

4.1.9 Summary of habitat requirements for sea trout parr

Physical habitat

Water velocity, depth, substratum and cover are important features of the habitat's suitability for sea trout parr. In summer preferred ranges are:

- Depth; <0.3 m
- Water mean velocity; 0.1–0.5 m/s
- Dominating substrate; 2–100 mm
- Stream wetted width; <6 m
- Slope; 0.5–3%
- Shade; >=10%
- Large woody debris; Increased abundance with LWD present

During winter coarse substrate or probably large woody debris providing cover becomes the most important habitat.

Spawning habitat criteria are narrower than the criteria for parr habitat. Good water intrusion into redds are crucial. Preferred ranges of physical features are:

- Depth; 0.15–0.45 m
- Water mean velocity; 0.2–0.55 m/s
- Dominating substrate; 16–64 mm

Temperature

The upper incipient lethal temperature for trout parr is 20–22°C, eggs are more sensitive (13°C).

Oxygen

Annual 50-percentile and 5-percentile of Dissolved oxygen (DO) for brown trout should be 9 mg O_2/l and 5 mg O_2/l, respectively.

Ultimate lethal levels of DO for salmonid species range from about 0.95 to 3.4 mg/l depending on temperature (i.e. within normal temperature range).

Suspended solids and turbidity

Suspended solids produce two main ecological effects in streams that can affect fish; increased turbidity of the stream water, and increased siltation of stream beds.

- Water quality standards allowing maximum increases of 5 NTU units above ambient turbidity in clear coldwater habitats provide relatively high protection for salmonid fish.
- Even at so low levels as 1 FNU negative effects on parr abundance has been noted.
- It is suggested that <5% of fines (<1 mm) in redds are tolerable levels.

pH

Hatching roe, yolk-sac fry and especially smolts are the most sensitive stages to acidification.

- In waters with a pH of 5.8 or higher sea trout populations should be unharmed by acidification.

Aluminium (Al^{3+})

No values have been estimated for trout parr. For salmon smolts safe concentrations are <5 µg/l of inorganic aluminium (Al_i). At a pH >6.2 levels of inorganic aluminium are seldom a problem.

Ferro-iron (Fe^{2+})

In trout streams the ferro-iron concentration should be less than 0.5 mg/l.

Nitrate (NO_3^-)

A maximum level of 2 mg NO_3-N/l would be appropriate for protecting the most sensitive freshwater species.

Nitrite (NO_2^-) & Total-ammonium (NH_4^+ & NH_3)

It is recommended that both nitrate and total ammonia should be below 60 µg/l in short term exposures (days) to ensure salmonid production. In long term exposure (months) levels should be lower.

4.2 Mapping of trout parr habitat

It is unrealistic to map all of the habitat of the 1000 Baltic sea trout rivers and streams According to HELCOM Salar project) working at the macrohabitat scale (1–10 m resolution). Preferably it should be possible to work at higher scales, at least in order to identify reaches that should hold trout habitat. Below is presented habitat mapping at different scales.

4.2.1 At electrofishing sites

Electrofishing is often conducted over a large (>100 m^2) areas of the stream and the habitat may be complex, with both slow- and fast-flowing sections. Data from these studies are generally not well suited for estimating individual microhabitat preference, but may be used on a macrohabitat level for the population (see section 4.1.1).

To facilitate comparisons of electrofishing data from sea trout streams in the Baltic region it is essential to find a least common denominators with regard to description of the habitat.

Within the SGBALANST group the habitat descriptions performed by the field crew when electrofishing were compared. A total of 40 different characteristics of the site and its habitat were noted (Table 4). Important habitat features as e.g. large woody debris, if the river bed was in a natural state and water quality were not collected by all. Common for most countries were data on latitude and longitude of site, fished length, width and area, wetted width of river, average or typical depth, dominating substratum, second dominating substratum, dominating type of water vegetation, dominating type of riparian zone, water velocity and shade (Table 4). Normally, lengths and widths were measured to the nearest meter and depth to the nearest cm.

Dominating substrate was generally classified from fixed particle diameters, but different scales were used (Table 5). From these differing classifications it may be possible to combine classes into four categories:

- Fine <2mm
- Gravel 2–100 mm
- Stone 100–2000 mm
- Rock >2000 mm

Table 4. Site and habitat characteristics noted according to code of practice when electrofishing sea trout rivers in the different countries. Gray shaded rows indicate variables available from at least six out of seven countries.

	Denmark	Estonia	Finland	Latvia	Poland	Russia	Sweden
Location							
Latitude & Longitude	X	X	X	X	X	X	X
Altitude				X	X		X
Length, width and area							
Fished length	X	X	X	X	X	X	X
Fished width	X	X	X	X	X	X	X
Fished area	X	X	X	X	X	X	X
Wetted width	X	X	X	X	X	X	X
Depth							
Average depth	X	X	X	X	X	X	X
Max-depth	X	X		X		X	X
Substratum							
Dominating substrate	X	X	X	X	X	X	X
Second dom. substrate	X	X	X	X		X	X
No. of large woody debris		X		X	X	X	X
Water velocity and level							
Velocity	X	X	X	X		X	X
Water level			X	X		X	X
Water quality							
Water colour	X	X		X			X
Turbidity		X		X			X
Oxygen, pH, conductivity				X			
Conductivity			X				
Aquatic vegetation							
Dominating form of vegetation		X	X	X	X	X	X
Coverage	X	X					X
Stream maintenance	X						
Riparian zone							
Dominating type		X	X	X	X	X	X
Light and Temperature							
Shade	X	X	X	X	X	X	X
Water temperature		X	X	X		X	X
Air temperature			X			X	X
Weather			X				
Trout habitat							
Quality of parr habitat	X	X				X	X
Cover types of value to fish	X				X		
River bed in natural state			X				
Catchment							
Size of catchment							X
Distance to upstream lake						X	X
Distance to downstream lake						X	X
Proportion of lakes							X

Distance to source					X	X	X
Slope at site					X		X
Barriers to fish migration	X					(X)	X
Discharge							
Average annual discharge				(X)		(X)	X
Bedrock							
Type of bedrock		X					X
Climate							
Average air temperature, year							X
Average air temperature, Jan							X
Average air temperature, July							X

Table 5. Classification of substrate type at the electrofishing site from particle diameter (mm) in different countries.

Denmark		Finland		Estonia		Latvia	Poland		Sweden	
Peat						5 classes				
Clay				Clay						
Soft	-0,2 mm			Mud					Fine	<0,2 mm
Sand	0,2-2 mm	Organic/Fine	<2	Sand	0,2-2 mm		Sand	<2 mm	Sand	0,2-2 mm
Gravel	2-60 mm	Gravel	2-16 mm	Gravel	2-20 mm		Gravel	2-20 mm	Gravel	2-20 mm
		Stone1	17-64 mm	Stone1	20-200 mm		Pebbles	20-100	Stone1	20-100 mm
Stone	>60 mm	Stone2	65-256				Stone	>100 mm	Stone 2	100-200 mm
		Small boulder	257-1024 mm	Stone2	>200 mm				Boulder1	200-300 mm
									Boulder2	300-400 mm
		Large boulder	>1024 mm						Boulder3	400-2000 mm
		Rock		Monolithic stone					Rock	>2000 mm

Also with respect to water velocity the classification schemes differed (Table 6). Sweden and Finland had the same system, with only three classes, whereas Denmark and Estonia had more refined schemes. A joint system could be:

- Slow 0–0.2/0.25 m/s
- Moderate >0.2/0.25–0.5/0.7 m/s
- Fast >0.5/0.7 m/s

Table 6. Classification of water velocity at the electrofishing site in different countries.

Denmark	Finland		Estonia		Sweden	
Dried out						
Quiet			No flow	<0,1 m/s		
Slow	Slow	<0,2 m/s	Slow	0,1-0,25 m/s	Slow	<0,2 m/s
Moderate	Moderate	0,2-0,7 m/s	Moderate	0,25-0,5 m/s	Moderate	0,2-0,7 m/s
Good	Fast	>0,7 m/s	Fast	0,45-1 m/s	Fast	>0,7 m/s
Fresh						
Very fast			Very fast	>1 m/s		

A joint conclusion from the SGBALANST group was that, although differences in the amount, classification and quality of field data gathered it should be possible to compare habitats at electrofishing sites between different countries.

4.2.2 Field surveys

Trout parr habitat is described at electrofishing sites (see above), but in order to estimate the amount of trout parr habitat available in different rivers often a field habitat survey of the whole river is necessary.

There are some advanced techniques focussed on microhabitat selection by fish available. These are often referred to as instream flow methods. These methods assess preferred fish habitat from flow and site characteristics (channel shape, depth, velocity, sediment and cover). Two of the most well-known methods are IFIM and PHABSIM. IFIM (Instream Flow Incremental Methodology) and PHABSIM (Physical Habitat Simulation) works in a similar way, i.e. are designed to predict the microhabitat (depth, velocities, channel indices) conditions in rivers as a function of streamflow, and the relative suitability of those conditions to aquatic life. These techniques can predict available habitat at different flow, but may be site specific. Both methods requires extensive field data and are time- and cost-consuming (Spence & Hickley 2000). Another drawback is that other habitat features as e.g. water quality, siltation, shade, temperature and predation are/may be not included in the habitat modelling, factors that may be very important (see section 4.1). Further univariate habitat suitability curves overlooks the interactions between hydraulic variables, and between hydraulic variables and the structural elements of the reach (Ayllon *et al.* 2009).

It is suggested that macrohabitat features are used for field classification (habitat surveys) of trout habitat on a larger scale. However, the majority of the countries do not have a standardized protocol for these macrohabitat surveys.

Denmark

When the streams are surveyed (approx. every 7'th year) during late summer – early autumn a habitat quality score (0–5) for each size/age class: fry, 6 months old, 1+ and 2+ is determined.

The score depends on average and maximum water depth, average stream width, substrate composition and amount of cover and is determined on a semi-empirical basis. The score is given for the section where trout population is investigated, but this should be representative for a longer section of the stream and thus habitat quality is established for all streams and tributaries. However, only wadeable streams are electrofished and due to time limitation approximately 2/3 of all sites (at total of about 7000 sites) are monitored.

Estonia

In Estonia, there is no official national standard for river habitat survey or classification. However empirical macro habitat quality assessment for young-of-the-year (YOY) trout and salmon parr is done for all electrofishing sites. When the quality is assessed, the average stream width, dominating substrate and amount of cover is taken in to account. The best trout habitat should have 80 YOY parr/100 m2 and the lowest quality habitat up to 8 YOY parr/100 m2 in the autumn. In some rivers the entire habitat is assessed and mapped this way and the future plan is to map all sea trout habitat this way.

Finland

In Finland, no official system has been established for river habitat survey and classification. Reproduction areas in the most important sea trout and salmon rivers have been mapped mostly in the 1980s and 1990s using the habitat classification system presented by Karlström (1977) and Bergelin and Karlström (1985). The rivers and tributaries have commonly been mapped by a field crew of two persons moving downstream from the headwaters to the river mouth by canoe or by walking on the river bank. The mapping has been done in summer during low discharge. The habitat characteristics include water velocity (5 classes), coarseness of the bottom material (6 classes), water depth (4 classes), bottom vegetation (3 classes) and vegetation on the river banks (3 classes). The rivers have been divided on the basis of uniform water velocity in successive segments with different lengths. The segments have been recorded on the map with a scale of 1:20 000, and their area has been calculated according to the length and mean width of each segment. The dominating classes of bottom material, water depth, bottom and bank vegetation were documented in each segment. However, for bottom material and sometimes for other important variables also the subdominating class/classes are recorded. The status (natural, dredged or restored) of the river environment has been mentioned, too. In some brooks, also the length of the rapids in meters has been recorded. In large rivers, like the Tornionjoki, some variations in the velocity and depth have been applied in classifying the typical characteristics of the riffles and glides. No special classification for spawning or parr habitats has been used, only the area of the riffles, glides and pools has been reported for the mapped rivers.

Poland

There is no official national system of river habitat survey and classification in Poland. Nevertheless, Inland Fisheries Institute, which carries out monitoring of sea trout production and fish fauna of sea trout rivers, describes sites when electrofishing. This is described in section 4.2.1. There is also method of survey of a whole river based on a modified River Habitat Survey method. It includes detail characteristic of surrounding, channel, bottom, vegetation and human pressure on every 50 or 100 m section. Until now it is carried out for circa 90 km of rivers of the lower part of the Slupia River system.

Russia

There is no official national system of river habitat survey and classification in Russia. Nevertheless, The State Research Institute on Like and River Fisheries, which carries out monitoring of sea trout production and fish fauna of sea trout rivers, describes sites of electrofishing. There is also method of survey of a whole river during the walking along the river. It includes detail characteristic of surrounding, channel, bottom, vegetation and human pressure on every 100 m section. The field crew normally consists of two persons walking the river from mouth to headwaters. Each segment of the river (smallest unit is 100 m) is described in protocols. The segments may extend to kilometres if the river habitat and the riparian zone are uniform. Until now it is made for circa some dozens km of different rivers.

Sweden

In Sweden a national standard is present, the Swedish Biotope Survey (Halldén *et al*. 2002). Data from surveyed rivers are stored in a recently started national database. The Swedish Biotope Survey (SBS) aims at a description of the water habitat, the riparian zone, migration obstacles, tributaries and road crossings. The result may directly be used for planning of restoration of habitat or establishing of fishways.

The field crew normally consists of two persons walking the river, from mouth to headwaters.

Each segment of the river (smallest unit is 30 m) is described in five protocols. The segments may extend to kilometres if the river habitat and the riparian zone are uniform. The largest river system mapped so far is the River Emån where approximately 800 km were surveyed. A total of 317 artificial migration obstacles were found and 14% of the river length was classed as heavily channelized.

As the field data gathered is quite comprehensive, it takes four man-days per 6 km of river. This includes field work, preparation with interpretation of aerial photographs and other maps, as well as data storage. Therefore a light version of SBS is used when the aim is to just focus on trout habitat. Approximately 6–8 km of river length can be mapped using the light-SBS by a two person crew and day.

The trout habitat quality is classed in four categories (Table 7). The boundaries between classes are somewhat vague and the field crew undergoes training at annual training courses.

Table 7. Classification of trout habitat for spawning, parr and large trout (brown trout) according to the Swedish Biotope Survey (Halldén *et al.* 2002).

	Class 0	Class 1	Class 2	Class 3
Spawning area	No substrate, wrong velocity	Velocity ok, substrate missing	Velocity & substrate OK, but not optimal	Velocity 0.2–0.4 m/s; gravel-small stones
Parr area	Lack of correct depth, velocity, substrate and shade	Two out of four present	Three out of four present	Depth <0.3 m; Velocity 0.2–0.5 m/s; Substrate gravel-boulders, shade at >20%.(LWD present)
Large trout habitat	No places for large trout to stay.	Few places	Several places, not optimal	Several places; depth >0.5 m, large stones or boulders or LWD, undercut banks, shade, velocity 0.1–1 m/s

SBS has been used as a basis of a trout smolt production model (Nilsson *et al.* 2010). The model combines SBS with electrofishing data. The accuracy is within ±25% when compared with time series from the smolt trap in River Åvaån in Sweden (op. cit.).

No information on river habitat survey systems was available from Germany, Latvia and Lithuania.

4.2.3 Use of GIS

At a larger scale trout habitat may be indicated using maps and Geographical Information Systems (GIS). Simple characteristics that may be derived from maps are correlated to population occurrence (Figure 4) and abundance (Figure 7).

The ultimate factor structuring stream fish communities in streams may be water velocity. This is determined by slope and friction against bottom and shores. This means that a larger volume of water (increased stream width and depth) will have a higher velocity at a comparable slope. Catchment area, average flow, wetted width and slope can be used as proxies for water velocity. Slope has been proven an important characteristic of streams and fish distribution may be predicted from it (Huet 1959, Wang *et al*. 2003, Pont *et al*. 2005).

Modelling spatial distribution of salmonid occurrence in streams using different techniques (e.g. multiple regression, logistic regression, neural networks, classification trees, hierarchical Bayesian models) together with geographic information system (GIS) tools has proven successful, but normally only presence/absence has been predicted with good precision (McCleary & Hassan 2008, Clingerman *et al*. 2007, Rahel & Nibbelink 1999, Wyatt 2003). Often catchment size, slope (gradient) and water temperature were important characteristics in these models (op. cit., Zorn *et al*. 2002, Pont *et al*. 2005).

But relative abundance has been predicted for some species using GIS. Wissmar *et al*. (2010) found that slope was a good estimator of coho salmon parr densities in Alaska streams. Stanfield *et al*. (2008) modelled occurrence and abundance of salmonids in Lake Ontario tributaries. GIS-derived landscape features were the best predictors of densities of rainbow and brook trout, whereas in-stream habitat features (proportion of riffles and pools, substrate, cover, and stream temperature) surveyed in the field produced the best predictive model for brown trout abundance. Lamouroux & Capra (2002) and later Ayllon *et al*. (2009) found a good correlation between the Froude number and the Reynold number and brown trout habitat selection pattern. To calculate these variables depth, mean velocity and wetted width are required. Creque *et al*. (2005) found in a similar study in Michigan rivers that site depth was negatively related to all salmonid densities, and it could not be estimated from GIS.

Heggenes *et al*. (2002) concludes after studying habitat use by Atlantic salmon and brown trout parr in south-west England streams that both species are flexible in their habitat selection depending on habitat availability. Habitat selection patterns may be stream specific.

Wang *et al*. (2003) found that reach variables (e.g. slope, shade, bank-full depth and width) explained more of stream fish assemblages distribution than did watershed characteristics (e.g. slope, area, elevation, land use), indicating the need for reach sampling in the field.

Gosselin *et al*. (2010) demonstrated the large variation of available habitats (runs and glides) with water flow in the River Tern, England. Available habitat may vary considerably during the year.

4.2.4 Conclusions

It may be concluded that accurate trout habitat classification generally requires field studies, but GIS may be a valuable tool for identifying reaches with potential for trout parr. It is probable that a combination of GIS data and spot sampling at a number of sites will be sufficient for a river habitat survey. As no such common system exists today, the SGBALANST group recommends field surveys.

A joint field survey mapping system can be constructed easily as most national systems are quite comparable.

4.3 A common classification system of trout parr habitat

4.3.1 4.3.1 Development of system

Index Rivers for sea trout can be established in streams with existing annual monitoring of recruitment (electrofishing), counting of smolts and spawners/redds. Electrofishing data will be required for the application of the stock-recruitment assessment of Index Rivers also in other rivers (as many rivers only have electrofishing monitoring programmes). To be able to compare the Index River electrofishing sites with sites in other rivers a simple way of habitat classification is required.

Electrofishing field data describing the sampled site was compared between countries. It was found that six environmental factors were quantified by all members in the field or could be added from maps:

- stream wetted width
- slope of investigated section (estimated from maps)
- water velocity
- average/dominating depth
- dominating substratum
- shade

Through the literature review (section 4.1.1), earlier work in Poland (Piotr Debowski), a recent evaluation of Swedish data (Degerman & Sers 2010) and expert judgement of the SGBALANST group, the suitability of each of the six environmental factors for trout parr was determined. The suitability ranged from 0 to 2, with 2 indicating the highest habitat quality. Smaller streams, with a slope of 0.5–3% and a bottom substrate dominated by gravel and small stones (approx. 20–200 mm) had high macrohabitat quality (Table 8). As for the substrate a bottom dominated by fine particles (<0.2 mm) was considered a bad habitat (habitat score=0), whereas sand (0.2–2 mm) or coarse stones and boulders (>200 mm) was given a habitat score of 1. The water velocity is normally only estimated, and not actually measured, in the field. Suggested classes are slow/still (<0.2 m/s), moderate (0.2–0.7 m/s) and fast (>0.7 m/s).

Table 8. Suggested habitat scores for the six common field descriptors of habitat quality.

	------------------------------------Habitat score----------------------------------		
	0	1	2
Wetted width of stream (m)	>10	6-10	<6
Slope (%) of section	<0.2 & >8	0.2–0.5 & 3–8	>0.5-<3
Water velocity class	Slow/still	Fast	Moderate
Average/dominating depth (m)	>0.5	0.3–0.5	<0.3
Dominating substratum	Fine	Large stones, boulders or sand	Gravel-Stone
Shade (%)	<10%	10–20	>20

The sea Trout Habitat Score (THS) is simply all the individual scores of the six descriptors summed for each site:

THS = width + slope + velocity + depth + substrate + shade

The score may range from 0 to 12.

4.3.2 Testing of system

The suggested trout macrohabitat score was tested on southern (from the county of Uppsala to Skåne) Swedish coastal streams with a catchment area below 1000 km^2. In total, the trout macrohabitat score (THS) could be calculated at 3213 fishing occasions. The abundance of trout parr (all ages) followed the score (Figure 9, ANOVA $F_{10,3202}=80$, $p<0.001$). Salmon parr abundance did not increase with the THS (Figure 10).

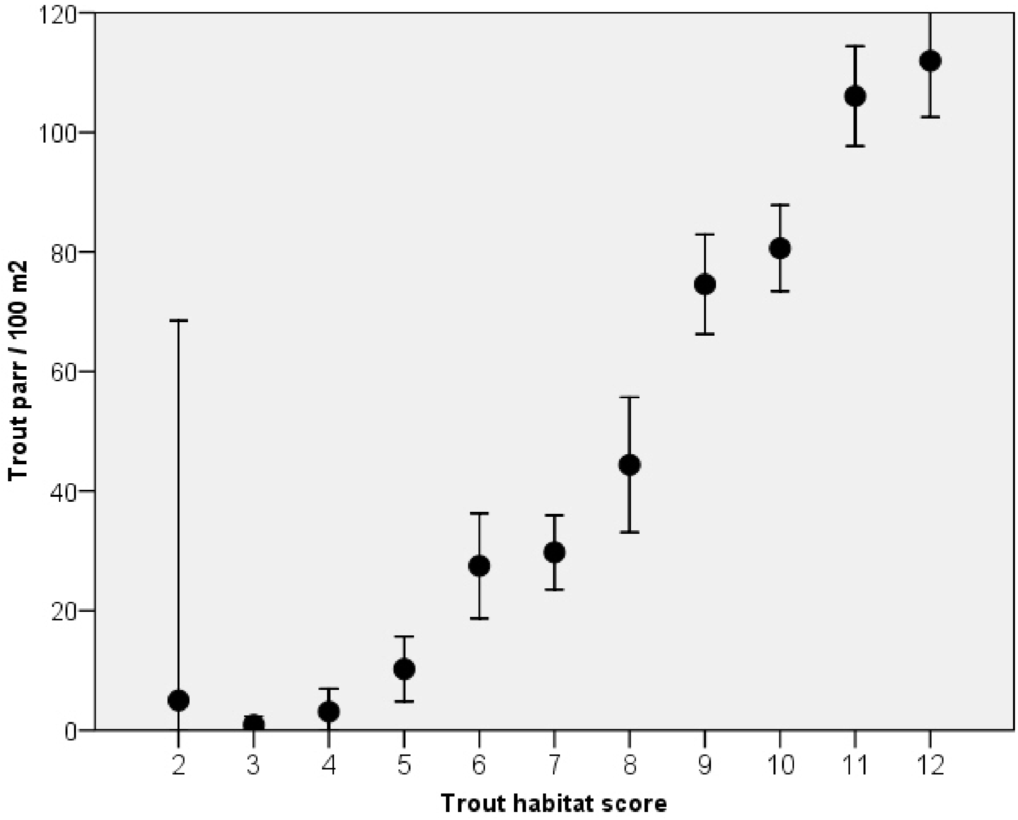


Figure 9. Average abundance of trout parr (±95% confidence interval) for each trout macrohabitat score class (n=3213 fishing occasions from southern Sweden).

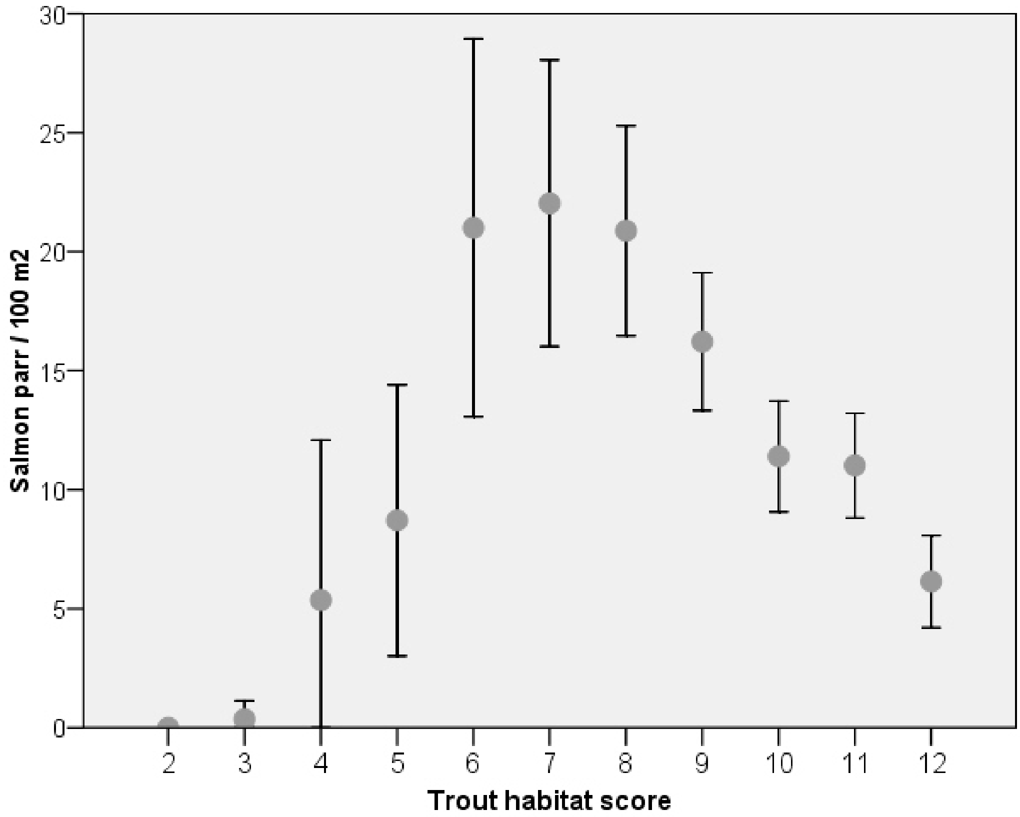


Figure 10. Average abundance of salmon parr (±95% confidence interval) for each trout macro-habitat score class (n=3213 fishing occasions from southern Sweden).

The THS was also tested on data from Danish streams. Data included were from 2008–10 (a few sites goes back to 2005) and also streams outside the ICES area of the Baltic were included. Whenever there was doubt about habitat quality class this was estimated conservatively - e.g. substrate is in many cases given with equal percentage cover for more groups (two or more groups co-dominate) and in those cases the lower value was chosen. Data on stream gradient was not available so this descriptor was omitted. Thereby the maximum values was 10. Also Danish data showed that THS is a good indicator of habitat value for sea trout (Figure 11).

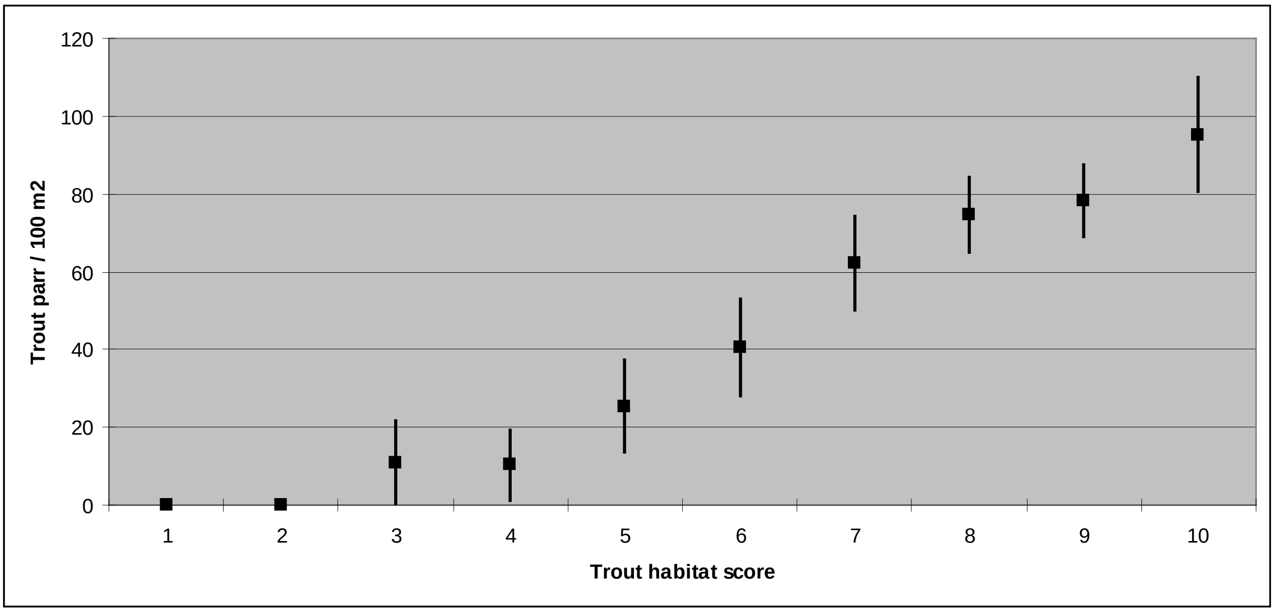


Figure 11. Average abundance of 0+ trout parr (±95% confidence interval) for each trout macrohabitat score class in fishing occasions (n=1831) from Denmark (not exclusively Baltic area). Macrohabitat does not include slope, and therefore the maximum value is 10.

It is suggested to have a final trout parr habitat score of four classes. Some countries were doubtful about how to calculate slope. As the data from Denmark showed it can be omitted and THS may be calculated using only five descriptors.

If slope is included, from the results in Figure 9, the classes are:

0	= THS <6
1	= THS 6-8
2	= THS 9-10
3	= THS 11-12

If slope is omitted, from the results in figure 11, the classes are:

0	= THS <4
1	= THS 5-6
2	= THS 7-8
3	= THS 9-10

4.3.3 Recommendations

It is suggested that electrofishing sites used in the assessment work of ICES shall be classed as trout habitat using THS in four classes (0–3). This should preferably be done using the method described above taking into account wetted width,water velocity, average depth, substrate and shade. Also slope may be taken into account. If detailed information is not available expert judgement can be used for the classification.

4.4 Towards assessment

SGBALANST has suggested that assessment of Baltic trout populations should be undertaken and that Index Rivers are required. This would allow stock-recruit parameters to be followed precisely, providing much needed information on smolt production, spawning population, parr-smolt survival and influence from environmental variables. Below (section 4.4.4) is a suggested list of Index Rivers.

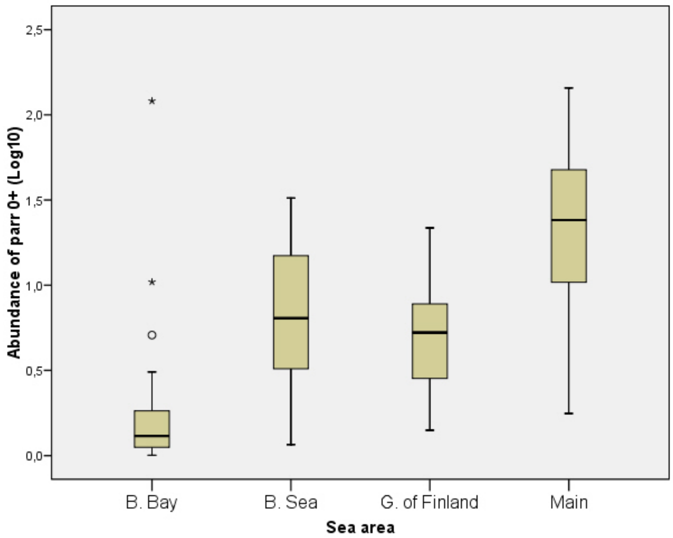
However, very few rivers today have a complete monitoring of ascending spawners, recruitment and smolt production. Awaiting the establishment of Index Rivers it is suggested that the work of WGBAST is concentrated on improving the model for estimation of optimal parr densities (carrying capacity) of sea trout in rivers with good habitat that has been produced (ICES 2009). This would allow electrofishing results from individual sites in rivers to be compared with an expected optimum (section 4.4.2) and trends in recruitment to be detected (4.4.3).

4.4.1 Assessment units

Ideally, Index Rivers should be established in each region (ICES subdivision) where trout populations exist under uniform conditions with respect to climate, fishing pressure, migration patterns and sea and freshwater habitats. However, today few suitable candidate rivers exist. It would be more realistic to first form larger assessment units, which could later be divided further if deemed appropriate.

There is not sufficient data from genetic monitoring to use as a basis for forming assessment units. Through the previous work of SGBALANST (ICES 2008, 2009) the Bothnia Sea, Bothnian Bay and Gulf of Finland (ICES subdivisions 30, 31 and 32) have been pointed out as highly separate units with respect to stock status and migration patterns. However, in the SGBALANST report 2009 it was concluded that all sea areas had at least one known population, where at least some fish migrated between sea areas. In addition it was stated that migration in many populations was unknown. In a recent evaluation of Swedish Carlin-tagging studies it was found that hatchery-reared smolts stocked in Bothnian Bay and Bothnian Sea were recaptured in the same areas (Degerman *et al*. in prep.). 97% of all recaptures from releases in Luleälven and Skellefteälven in the Bothnian Bay area were made in the same area. The corresponding figures for releases in the Bothnian Sea area were 94.4–100% (six different rivers). Thus, using these relatively confined areas (including Gulf of Fisnland) as assessment units seem promising. It is suggested that the remaining part of the Baltic including the Sound will form a fourth assessment unit; Baltic Main.

Apart from migration patterns and stock status, also abundance of sea trout parr differed between Baltic Main and the more northern areas (Figure 12). However, a larger span of parr abundance was evident for Baltic Main indicating the need for splitting this assessment unit in the future. This was mainly due to weak recruitment in the south-eastern part of the Baltic main (ICES 2009). Trout populations assessed together should basically experience same fishing pressure and have comparable status. As it is, there are differences in fishing pressure in the Baltic Main, different accessibility to spawning/nursery areas (in Poland there are many water power constructions as compared to Denmark) etc.



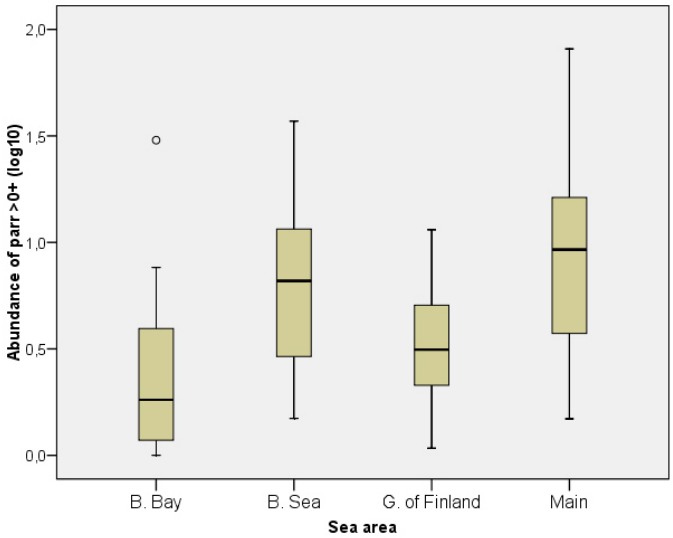


Figure 12. Box-plot of average abundance (log-10 numbers per 100 m²) of 0+ (above) and >0+ (below) sea trout parr in four suggested assessment units. Data from 184 rivers compiled by SGBALANST.

4.4.2 Estimation of optimal parr densities; recruitment status

The bulk of data for the assessment will stem from electrofishing in natal streams. Through electrofishing data it should in the future be possible to compare the actual parr densities on a site with an expected optimal recruitment. In the previous work of SGBALANST (ICES 2009) a simple model was constructed from the data on recruitment gathered. Densities of sea trout parr depend on climate and the size of the river (op. cit.). As data on climate (e.g. average air temperature) were not available for all sites, longitude and latitude were used as proxies. Longitude represents a gradual shift from oceanic to continental climate, whereas latitude represents a gradient from warm to cold climate. For each river also the size of the river, classified in four classes, was used (1=<100, 2=100–1000, 3=>1000, 4>10 000 km²). Using these factors the effect of different climate and catchment size was accounted for. Only rivers with good water quality and good habitat as reported by the members of SGBALANST were selected for modelling. Only data from the period 2000–2008 were used as this period was available from all members that had electrofishing data. Further, only stable populations were used, i.e. those with a CV (Coefficient of variation) below 50% (calculated from log10-transformed river averages of trout parr abundance different years). This was done to eliminate rivers with large fluctuations, e.g. some rivers in the Gulf of Finland that had limited ascent of spawners in the autumn of 2002 due to low water flow. Data from ICES subdivision 31 was not used as it was the opinion of the Finnish and Swedish delegates that these stocks were extremely small, well below carrying capacity. A few rivers with stocking of parr were included as it was suggested that the stocking was done to levels that were not above carrying capacity. Using the resulting simple model, the abundance of parr in rivers with good ecological conditions and stable populations could be predicted from latitude and catchment size class, but with only 32.5% explained variation.

The observed abundance for each river and year was divided by the predicted abundance and expressed as percentage; recruitment status. Rivers with abundance as predicted would then get a recruitment status of 100%, and rivers with a lower abundance than predicted would have lower percentages. It must be stressed that a recruitment status of 100% does not mean that a maximum production of recruits is present. It is mere an index of what was the best production in rivers with good habitat during 2000–2008.

New data on trout parr densities and habitat quality has been compiled recently through the HELCOM Salar project. In these data the status of the sea trout populations are estimated by the national experts, and the actual smolt production is guesstimated in proportion of the maximal production. This should allow a more precise model of expected abundance in rivers with populations in good status to be established. Another advantage is that the new data set also includes more figures of catchment size and higher resolution in water quality and habitat quality status.

Recruitment status is not an assessment tool, but may aid in preliminary stages of the establishment of assessment to give indications of actual recruitment success.

4.4.3 Trend rivers

At present sea trout parr densities are reported annually to the WGBAST. In the report of 2010 (ICES 2010) tables 7.2.2.3 (Sweden), 7.2.2.4 (Finland), 7.2.3.4 (Estonia), 7.2.3.5 (Russia), 7.2.4.1 (Emån, Sweden), 7.2.4.2 (Lithuania), 7.2.4.3 (Poland), 7.2.4.4 (island of Bornholm, Denmark) provide parr densities of different rivers or regions. The data is given as averages of all electrofishing stations in the river or region.

These data are especially suited for detecting trends in recruitment. It is suggested that the trend (log10-abundance of 0+ and >0+) in each river is calculated (Pearson r) and that all trends in assessment units are compiled using Meta analysis, providing a summation of all trends strengths.

It is important to discuss the length of time series used to calculate the trend. The outcome may depend on whether the length of the time series is a few years (~half of the length of a trout generation), 5–7 years (~length of one generation), or decades. We propose a two-step analysis, initially with rivers with time series extending at least two trout generations to show long-term (decadal) development. The second step would focus on short-term trend. This should anyhow cover at least one trout generation in order to be able to distinguish fluctuations in year-class strength from actual trend.

To provisionally show the outcome of such an analysis, the average and 95%-confidence interval of Pearson r was calculated for each ICES subdivision where data was compiled from individual rivers by SGBALANST. Two regions with weak stocks (ICES 2009), subdivisions 30 and 31, showed increasing trends for trout parr >0+ (Figure 13). In the Gulf of Finland (subdivision 32), also with weak stocks, no regional trend was at hand. Instead of displaying Pearson r it is recommended that effect size is used. Subdivisions with a 95%-confidence interval separated from the 0-line had a significant trend. Significant trends were present in subdivisions 30, 31 and 32 (Figure 14).

Although such an analysis will not be a true assessment of stocks, it will, in combination with recruitment status (section 4.4.2), give good information on sea trout recruitment. Including only rivers/sites with good habitat quality, recruitment should reflect the stock status (number of spawners) of individual populations or populations in regions.

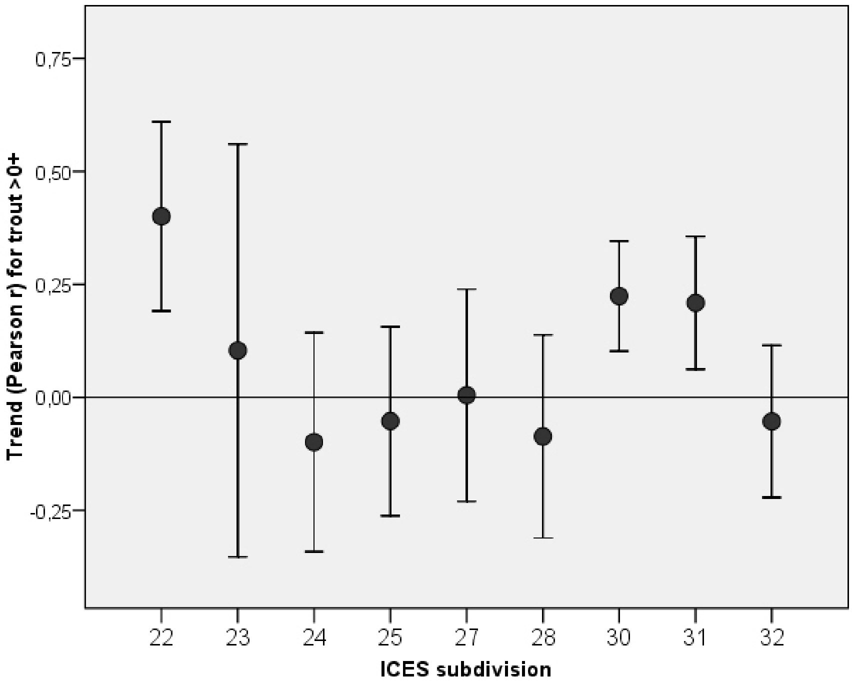


Figure 13. Pearson r, indicating trend in a time series, for trout >0+ parr abundance in 184 rivers around the Baltic Sea per ICES subdivision.

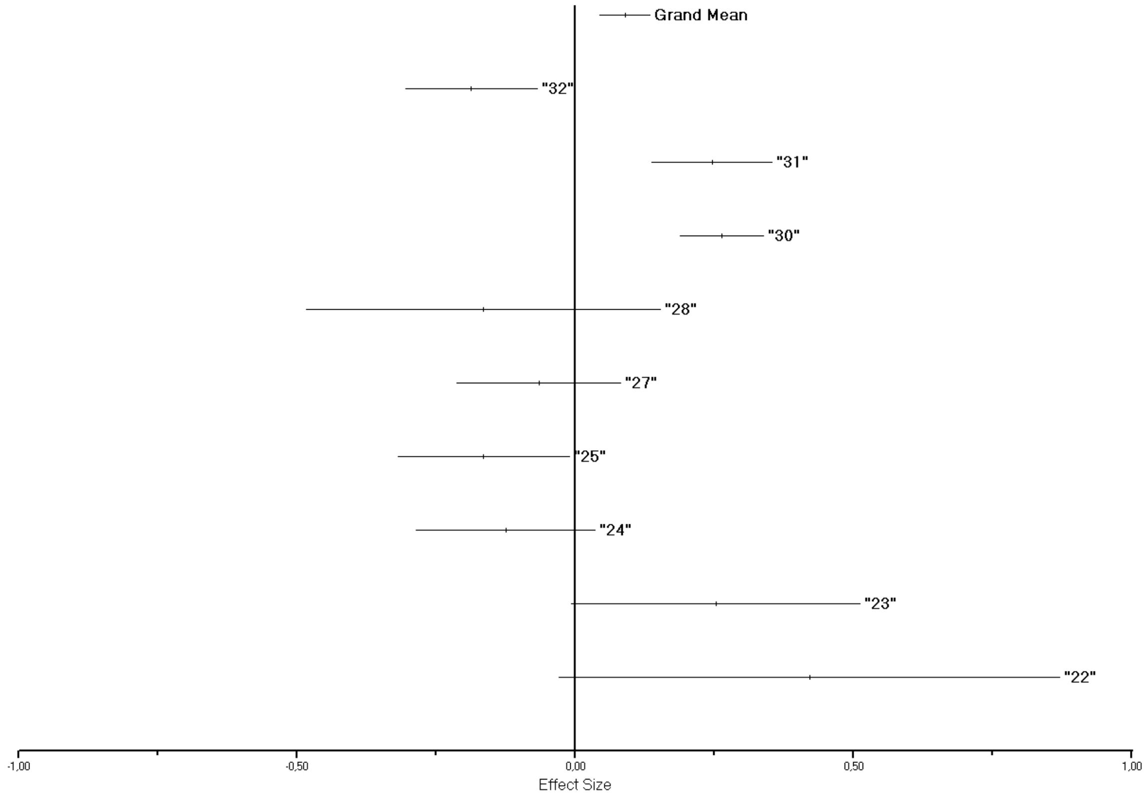


Figure 14. Effect size of for trend in trout >0+ parr abundance in 184 rivers around the Baltic Sea per ICES subdivision. Meta-analysis was used for calculations of effect size.

4.4.4 Suggested Index Rivers

Sea Trout Index Rivers should preferably be small (<1000 km^2) and dominated by sea trout, not salmon. Ascending spawners are counted in some of the larger salmon rivers. Ascending sea trout generally spawn in tributaries of these larger rivers, where no studies of recruitment are undertaken. Further the quality and quantity of sea trout parr habitat in such large systems are not mapped, and is difficult to map. Another problem with using monitoring in the large salmon rivers is that ascending fish often is monitored using automated counters, which would require image analysis for distinguishing sea trout from other detected species like salmon. The number and weight of females (needed for calculating egg deposition) would still be unknown, but may be estimated from literature data.

Unfortunately, only one Index River with electrofishing, trapping of smolts and spawners is available in a typical sea trout river. This is River Åvaån in Sweden (ICES subdivision 27, Baltic Main). Åvaån has a catchment area of 16 km^2 and an average annual smolt production of 650 smolts. Trapping efficiency has not been checked, but is expected to be high.

In the Swedish river Sävarån, Index River for salmon in subdivision 30, sea trout spawn in several tributaries. These are monitored by electrofishing, but only as a part of the follow-up program of liming operations, not as a part of the salmon monitoring. The latter is only carried out in the main stem. Mobile smolt traps (Rotary screw traps; EG Solutions, Oregon, USA) have been operated since 2005. Trapping efficiency (11–27% for sea trout parr) has been evaluated through mark-recapture experiments. Estimated sea trout smolt numbers ranged from 500 to 1500 but with high uncertainty in the estimates (Lundqvist *et al*. 2008). Ascending spawners are automatically counted (Vaci equipment) but the weight and proportion of female sea trout is not known. River Sävarån, in spite of the large catchment area of 1161 km^2, may qualify as an Index River if the sea trout parr habitat of the whole river system is mapped (N.B. this is not the same as salmon parr habitat). Further, characteristics as proportion of females and average weight of females must be assessed.

In the Baltic Main Mörrumsån is an index river for salmon in subdivision 25 (Table 9). Interestingly, salmon and sea trout spawn and use only the main stem of the river, while the sea trout production in tributaries is low. However, the habitat mapping is focussed on salmon and what proportion of the estimated salmon habitat that can be used by sea trout is not certain. If this was mapped and electrofishing stations arranged according to these results River Mörrum may provide good information on sea trout production.

In the Sound, subdivision 23, a smolt trap has been operating since 1998, but was initially built in the 1950s. The river is Kävlingeån (Sweden) with at catchment area of 1204 km^2. Salmon does not exist in the river. Electrofishing is carried out annually and the habitat has been mapped. However, no trapping of ascending spawners is performed (Table 9), but spent kelts are caught in the smolt trap in spring. Including this river would require establishing a system for counting of ascending spawners.

Finland also provides some potential Index Rivers. WGBAST already reports the existing time series from the Finnish sea trout rivers. Of these, Tornionjoki (subdivision 31) is already Index River for Baltic salmon. There is no Finnish Index River suggested for subdivision 29, due to the absence of wild sea trout rivers in the area, but for the Bothnian Sea (subdivision 30) River Isojoki may be a candidate although counting of smolts and spawners is lacking today (Table 9). In the Gulf of Finland the small Ingarskilanjoki is a potential Index River, with both electrofishing and smolt counting. Extending the monitoring in the suggested rivers to cover the rest of the variables of interest (smolt and spawners abundance) would require allocation of new resources (Table 9).

In the Russian river Luga, a salmon river in subdivision 32, sea trout spawn in several tributaries. These are monitored by electrofishing as a part of the sea trout monitoring. A floating smolt trap has been operated here since 2001 (in the lowest part of the River, but not in each tributary). Trapping efficiency (3–10% for sea trout parr) has been evaluated through mark-recapture experiments. Estimated trout smolt numbers range from 2000 to 8000. No trapping of ascending spawners is performed, but spawners are caught by trap during brood stock fishing. Including this river would require establishing a system for counting of ascending spawners.

In Denmark no index rivers are found. Only in relation to specific (limited period) studies information on smolt numbers have been collected and the same applies to trapping of adult spawners. It is unlikely that an index river will be established in a foreseeable future.

In Estonia no index rivers for sea trout are assigned. Smolt trapping is done only in one salmon river discharging in to the Gulf of Finland. The River Pirita has a catchment area of a 799 km^2 and had historically bigger salmon than sea trout population, therefore it is not well suited to be a sea trout index river. It is unlikely that an index river only for sea trout will be established.

In Germany, Latvia, Lithuania and Poland no sea trout index rivers were suggested.

Table 9. Suggested sea trout Index Rivers.

River	Country	ICES Subdiv	Catchment (km²)
Ingarskilanjoki	Finland	32	160
Luga	Russia	32	12800
Tornionjoki	Finland	31	40131
Sävarån	Sweden	30	1161
Isojoki	Finland	30	1098
Åvaån	Sweden	27	16
Mörrumsån	Sweden	25	3369
Kävlingeån	Sweden	23	1204

River	Electrofishing	Smolt	Spawners	Redds	Salmon Index River
Ingarskilanjoki	Yes	Yes	No	No	No
Luga	Yes	Yes	No	No	No
Tornionjoki	Yes	Yes	Didson	No	Yes
Sävarån	Yes	Yes	Vaci	No	Yes
Isojoki	Yes	No	No	No	No
Åvaån	Yes	Trap	Trap	No	No
Mörrumsån	Yes	Trap	Vaci	No	Yes
Kävlingeån	Yes	Trap	No	No	No

Summing up it is difficult to establish a program of Sea Trout Index Rivers with information on spawners, recruitment and smolt output in small rivers. Today only one river, Åvaån, directly qualifies. Several rivers may be candidates in the future, depending on if funding can be found for additional sampling.

4.4.5 Steps towards assessment

As stated above few rivers are potential Index Rivers as monitoring of spawners or smolt may be lacking. However, there are four suggested index rivers in subdivisions 30–32 and three in the Baltic Main (Table 9).

The work of SGBALANST has shown that some trout stocks are weak, primarily as indicated by low parr abundances and in some rivers by low numbers of spawners. This is further supported by declining return rates of marked stocked fish, with high proportion of fish caught before maturity. The ultimate cause for weak wild stock is not known and e.g. both degraded lothic habitat and by-catch of postsmolts in the fishery have been suggested. In an assessment, all stages of sea trout life must be monitored, from egg to returning spawner, to be able to identify what causes bad stock status.

Ideally, the survival from egg to spawner is known, as well as the main factors causing increased mortality. Also the survival from egg to parr, parr to smolt, from smolt to adult spawner, and from spawners to deposited eggs needs to be estimated (Figure 15).

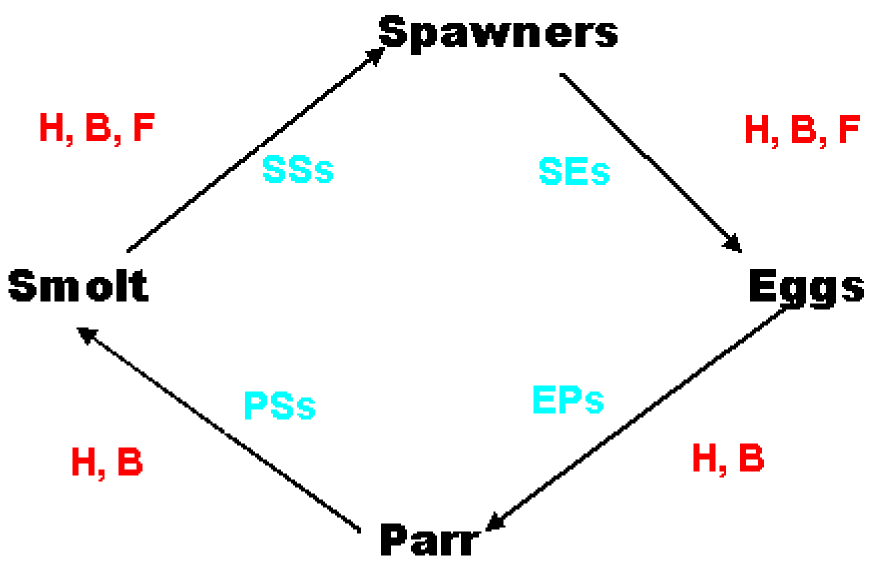


Figure 15. Conceptual simplified model of a sea trout population from egg to spawner. Each stage is affected by different driving forces; Habitat (H), Biotic interactions (B) and some also by Fishery (F). It is essential to estimate the survival between different life stages (e.g. survival from egg to parr; EPs) and to assess the effect of habitat, biotic interactions and fishery on survival.

It is suggested that PSs (parr to smolt survival), ESs (eggs to smolt survival) and even egg to spawner survival can be monitored in Åvaån. Unfortunately, this is the only river where a complete stock monitoring is possible (Table 10). Parr to smolt survival may be estimated at the most in 4–6 rivers (the higher figure if electrofishing in tributaries is initiated in some larger salmon rivers). The crucial sea survival, from smolt to returning spawner, may be estimated from only four rivers by counting the number of smolts and returning spawners. By adding tagging programmes of wild sea trout smolt the resolution of these data may be further enhanced. Such programs are lacking in all rivers. Detailed assessment of sea trout populations of the Baltic will require additional monitoring in the suggested Index Rivers.

Table 10. Survival between different life stages of sea trout that may be estimated in different sugegsted index rivers. * denotes rivers where extended electrofishing in tributaries are required for monitoring of sea trout.

River	Spawners to egg deposit.	Egg to parr	Parr to smolt	Smolt to spawners
Ingarskilanjoki			Yes	
Tornionjoki	Yes	*	*	Yes
Sävarån	Yes	*	*	Yes
Isojoki				
Åvaån	Yes	Yes	Yes	Yes
Mörrumsån	Yes		Yes	Yes
Kävlingeån			Yes	
	=======Freshwater survival==========			==Sea survival===

It is suggested that the future assessment work will be done in three steps, awaiting the establishment of Index Rivers.

1) Two means of estimating recruitment and trends in recruitment, recruitment status and trend rivers, based on electrofishing data is presented above. The data for this are already provided to the WGBAST.
2) Sea survival has been pointed out as one cause of weak stocks and should be evaluated using available smolt production estimates in relation to returning spawners. This could be done for the present salmon Index Rivers in a few years as well as for river Åvaån. Tagging of wild smolts would increase the information gathered.
3) Establishing sea trout Index Rivers will require additional funding due to the need of supplementing existing monitoring programmes. It should be investigated if international funding is feasible, e.g. through EU.

5 Summary and conclusions

Previously the SGBALANST group has concluded that the status of the sea trout populations in the Bothnian Bay and in the Gulf of Finland is in a severe state with very low parr densities and small runs of spawners into the rivers. Also stocks in Bothnian Sea and the southeast of the Baltic Main are regionally weak. In most other parts of the Baltic the trout populations seem to be in a reasonably good state. The main reason for the poor status of the northern sea trout populations appears to be the by-catch of trout post smolts in a heavy net fishery targeting mainly whitefish in the Bothnian Bay and Bothnian Sea area and also pikeperch in the Gulf of Finland. But, also deterioration of the freshwater habitat poses threats. The SGBALANST group found that the status of the sea trout does justify ICES assessment, preferably by establishing sea trout Index Streams.

Today the majority of data is on parr densities (recruitment; monitored by electrofishing). A comparison of habitat description at electrofishing sites was performed between countries and it was concluded that comparable data was present allowing sites to be compared with regard to habitat features (wetted width, velocity, average depth, dominating substratum, shade – slope may be included).

Trout parr habitat is described at electrofishing sites, but in order to estimate the amount of trout parr habitat available in different rivers often a field habitat survey of the whole river is performed. The group found that no joint system for this was present but different national strategies were presented.

To enable comparisons of parr densities among sites, rivers and regions habitat criteria for sea trout of parr habitat and spawning areas was established as a part of the work 2010/2011. Also included in the habitat criteria were temperature, sediment deposition and chemical constituents of the water.

From this a common sea trout parr habitat classification system (trout habitats score; THS) was constructed. It has been tested on Swedish and Danish data and predicts trout parr densities with good accuracy. Hereby, parr densities may be predicted from habitat characteristics.

The group suggests four main assessment units, based on migration patterns and parr densities; Bothnian Bay, Bothnian Sea, Gulf of Finland and Baltic Main. The latter may need to be split in smaller parts in the future.

There are seven suggested Index Rivers, but only one has monitoring of parr, smolt and spawners. The other rivers will need additional monitoring, e.g. the salmon index rivers Tornoinjoki and Sävarån where electrofishing is not carried out in tributaries where sea trout spawn. Before assessment can be performed, funding for the additional monitoring will have to be solved. Also tagging of wild sea trout smolts would be essential for estimating sea survival.

Awaiting true assessment the group suggested two means of estimating recruitment and trends in recruitment, recruitment status and trend rivers, based on electrofishing data.

6 Recommendations

Among the focal things to be considered is how to proceed from the step of assessing the current status of stocks and describing the optimal freshwater habitat (which has been in focus of SGBALANST). For management, it would be crucial to be able to:

- identify the factors which are keeping stock status below 'optimal';
- rate the relative importance of these factors, especially fishery;
- give guidelines for recommending management actions by which these factors can be affected and stock status improved.

The quantification of spawning success (i.e. parr densities) in freshwater would indicate freshwater habitat quality and even the factors which are affecting it. Likewise total sea survival would indicate if the sea survival is too low for the stock to improve. This apparently needs to be somehow complemented with information on fishing pressure, in order to reveal the relative importance of this factor and thus the need for fishing regulations. All this points towards the need to establish Index Rivers with good-quality input/output data, complemented with population-specific catches in fisheries of adjacent sea areas.

It is suggested that such an assessment approach is best conducted within the ICES framework, in collaboration with national institutes. The crucial thing will be funding of the additional monitoring, whereas the assessment can be performed within the regular work of WGBAST.

It is suggested that the future work will be done in three steps, awaiting the establishment of Index Rivers.

1) Awaiting true assessment the group suggested two means of estimating recruitment and trends in recruitment, recruitment status and trend rivers, based on electrofishing data. The data for this are already provided to the WGBAST. Using the new data from the HELCOM project Salar the recruitment status model may be enhanced.
2) Sea survival has been pointed out as one cause of weak stocks and should be evaluated using available smolt production estimates in relation to returning spawners. This could be done for the present salmon Index Rivers in a few years as well as river Åvaån. Tagging of wild smolts would increase the information gathered, as well as investigations of by-catch of trout in other fisheries.
3) Establishing sea trout Index Rivers will require additional funding due to the need of supplementing existing monitoring programmes.

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