Stock Annex: Salmon (*Salmo salar*) in subdivisions 22–31 (Main Basin and Gulf of Bothnia) and subdivision 32 (Gulf of Finland)

Stock	Salmon in SD 22–31 (Main Basin and Gulf of Bothnia) and SD 32 (Gulf of Finland)
Working Group	WGBAST Baltic Salmon and Trout Assessment Working Group
Last updated	April 2020
Revised by	WGBAST (Inter-benchmark in 2012–2013, Benchmark in 2017 and annual meetings in 2019 and 2020)

Timeline of revisions:

- January 2013: first Stock Annex was produced during IBPSalmon (ICES, 2013).
- May 2014: minor updates of the Stock Annex, including updates of the list of wild salmon rivers and procedures for estimating harvest rate.
- April 2019: extensive updates of the Stock Annex based on outcomes of a benchmark held in 2017. Several model-related changes, including method for parameterisation of stock–recruit relationships and change of software platform for running the assessment model, are now described. In addition, some background information on fisheries, data collection and assessment methods were moved from the working group report to the Stock Annex.
- April 2020: minor updates. A description of how trolling catches are accounted for in the model has been added in section C.1.9. In addition, the paragraphs about dioxin (A.2.6) and M74 (A.3.1) have been updated to a minor extent, and Figure A.1.1.1 has been revised.

Last Benchmarked	WKBALTSalmon (ICES, 2017)

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A. General

A.1 Stock definition

The Baltic salmon is characterized by a marked population genetic structure. Previous studies indicate clear genetic differences both between salmon from different rivers located within restricted geographical areas and between groups of rivers on a larger geographical scale. According to the results of Säisä *et al*. (2005), there are three main groups of salmon populations in the Baltic Sea: 1) Gulf of Bothnia populations, 2) populations in southern Sweden, and 3) eastern populations (Gulf of Finland and eastern Main Basin). These groups or lineages are assumed to mirror three distinct post-glacial colonization events. About 5% of the total genetic diversity of the Baltic salmon is explained by differences between rivers within groups, whereas 6% is explained by differences between the lineages (Säisä *et al*., 2005).

Because of the pronounced population genetic structure, the Baltic Sea could not be regarded as one single assessment or management unit. Instead, the assessment is focused on restricted assessment areas (units) and rivers, and management objectives are evaluated both on an assessment unit level and on a river-by-river basis. Throughout this document, we are using the term "river stock" for salmon that belongs to a particular river. In most cases, river stocks most likely correspond to biological populations which lend support for this level of division from a conservation genetic perspective. However, it should be noted that some larger rivers may harbour several salmon subpopulations that are genetically separated spatially and/or temporally (Lind *et al*. 2015). There may also be cases where several smaller, closely situated rivers together constitute one single biological population because of significant gene flow.

A.1.1 Definition of assessment units within the Baltic Sea area

Within the Baltic Sea area, currently six different assessment units (AUs) have been established (Figure A.1.1.1). The grouping of rivers within an assessment unit is based on management objectives and biological and genetic characteristics of the river stocks contained in a unit. The partition of rivers into assessment units needs to make sense from a management perspective. River stocks of a particular unit are believed to exhibit similar migration patterns at sea. It can therefore be assumed that they are subjected to the same sea fisheries, experience the same exploitation rates and are affected by management of sea fisheries in the same way. In addition, the genetic variability between river stocks of an assessment unit is smaller than the genetic variability between river stocks of different units (see above). Although the rivers of assessment units 5 and 6 are relatively small in terms of their production capacity compared with rivers in the other assessment units, they are very important from a conservation perspective because of their unique genetic background.

The six assessment units in the Baltic Sea consist of:

1) Northeastern Bothnian Bay river stocks, starting at Perhonjoki up till the river Råneälven.

2) Western Bothnian Bay river stocks, starting at Lögdeälven up to Luleälven.

3) Bothnian Sea river stocks, from Dalälven up to Gideälven and from Paimionjoki up to Kyrönjoki.

4) Western Main Basin river stocks, i.e. southeastern part of Sweden.

5) Eastern Main Basin river stocks, i.e. rivers in Estonia, Latvia and Lithuania.

6) Gulf of Finland river stocks.

Wild river stocks belonging to each assessment unit are listed in the next section.

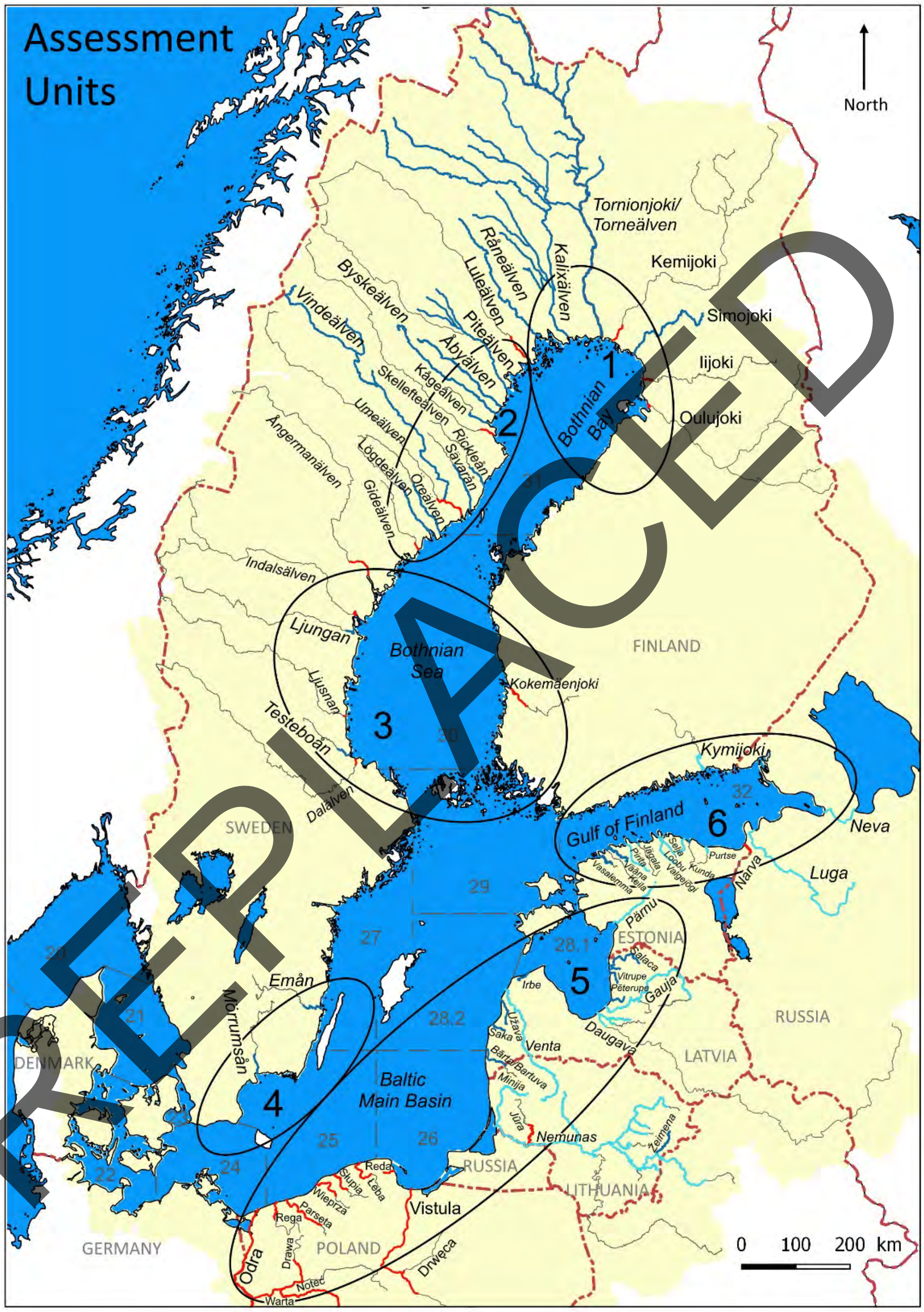

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Figure A.1.1.1. Grouping of salmon river stocks in six assessment units in the Baltic Sea. The genetic variability between river stocks of an assessment unit is smaller than the genetic variability between river stocks of different units. In addition, the river stocks of a particular unit exhibit similar migration patterns. Wild salmon rivers (dark blue), mixed salmon rivers (light blue), reared salmon rivers (red), river stretches not accessible for salmon (grey).

A.1.2 Division of rivers into wild, mixed, reared and potential

The Baltic salmon rivers may be divided into four main categories: those holding either wild, mixed or reared river stocks and those owing potential to hold (but which currently do not hold) a wild or mixed river stock. This categorization scheme (see Table A.1.2.1) is used when discussing data from particular rivers, and it has been defined and discussed in earlier reports from ICES (e.g. ICES 2008b; 2018). The same scheme has also been used for determining which wild rivers should be included in the yearly assessments of stock status performed by the working group.

Briefly, wild salmon rivers (i.e. rivers holding wild river stocks) should be self-sustainable with no or very limited releases of reared fish (see ICES 2018 for more details); mixed rivers have some wild production but are subject to considerable stocking and it is often unclear if they could become self-sustainable (however, in some larger river systems currently defined as mixed, individual tributaries like Zeimena in Nemunas river basin may have self-sustainable wild populations); reared rivers currently have no possibility of holding self-sustaining river stocks and thus are entirely dependent on stocking; river stocks in potential rivers are currently not regarded as self-sustainable but are believed to have a fair chance of becoming so in future (Table A.1.2.1). It should be noted that during the re-establishment process, a potential river may first become a mixed river before it finally fulfils the criteria for becoming a wild river. In the total Baltic Sea (AU 1–6), there are currently 58 salmon rivers out of which 27, 14 and 17 are considered as wild, mixed and reared, respectively. In addition to these, a relatively large number of potential rivers (several with ongoing reintroduction programmes or occasional reproduction) exist.

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Table A.1.2.1. Classification criteria for wild, mixed, reared and potential salmon rivers in the Baltic Sea.

Category of salmon river	Management plan for salmon stock in the river	Releases	Criteria for wild smolt production
Wild	Self-sustaining	No continuous releases	>90% of total smolt prod.
Mixed	Not self-sustaining at these production levels	Releases occur	10–90% of total smolt prod.
Reared	Not self-sustaining	Releases occur	<10% of total smolt prod.
Potential leading to category wild	Lead to self-sustaining river stock	Releases occur during re-establishment	Long-term >90% wild smolt prod.
Potential leading to category mixed	Not self-sustaining river stock	Releases occur	Long-term 10–90% wild smolt prod.

Wild and mixed salmon rivers in the Baltic Sea

Current wild salmon rivers in the Baltic Sea are listed below per country and assessment unit (AU). Several of the rivers were also listed in the former IBSFC Salmon Action Plan.

- Finland: Simojoki (AU 1)
- Finland/Sweden: Tornionjoki/Torneälven (AU 1)

- Sweden: Kalixälven (AU 1), Råneälven (AU 1), Piteälven (AU 2), Åbyälven (AU 2), Byskeälven (AU 2), Kågeälven (AU 2), Rickleån (AU 2), Sävarån (AU 2), Ume/Vindelälven (AU 2), Öreälven (AU 2), Lögdeälven (AU 2), Ljungan (AU 3), Testeboån (AU 3), Emån (AU 4), Mörrumsån (AU 4)
- Estonia: Kunda (AU 6), Keila (AU 6),Vasalemma (AU 6),
- Latvia: Salaca (AU 5), Vitrupe (AU 5), Peterupe (AU 5), Irbe (AU 5), Uzava (AU 5), Saka (AU 5)
- Latvia/Lithuania: Barta/Bartuva (AU 5)

Current mixed salmon rivers in the Baltic Sea are listed below per country and assessment unit (AU). Some of these may in future become wild rivers.

- Latvia: Gauja (AU 5), Daugava (AU 5), Venta (AU 5)
- Lithuania: Nemunas river basin (AU 5)
- Estonia: Purtse (AU 6), Selja (AU 6), Loobu (AU 6), Valgejõgi (AU 6), Jägala (AU 6), Pirita (AU 6), Vääna (AU 6), Pärnu (AU 5)
- Russia: Luga (AU 6)
- Finland: Kymijoki (AU 6)

More information about wild, mixed and reared rivers can be found in Tables C.1.2.1, C.2.1 and C.3.1.

Potential rivers

Several countries have officially appointed potential salmon rivers as suggested in the former IBSFC Salmon Action Plan. Mostly, these rivers are old salmon rivers that have lost their salmon population. Restoration in potential salmon rivers was started in some countries in different ways and with varying efforts. The goal of the restoration is to re-establish natural reproduction of salmon.

Most of the potential rivers show only low and irregular wild reproduction despite even massive stocking programmes and other rebuilding efforts. Several problems in various phases of salmon's life cycle may adversely affect restoration measures (ICES 2017a), but their relative importance is difficult to assess. A more thorough analysis, e.g. comparing more and less successful cases of restoration is needed.

Testeboån (AU 3) and Kågeälven (AU 2) are two successful examples of salmon reintroduction. The original salmon populations in Testeboån and Kågeälven became extinct in the 1960s and 1870s, respectively. Around 1990 reintroduction programmes based on releases of reared salmon (mainly fry) from neighbouring rivers were instigated in both rivers. The last releases of newly hatched fry occurred in 2004 (Kågeälven) and 2006 (Testeboån). Presence of salmon parr in subsequent years demonstrated occurrence of natural spawning. After long enough time periods, when wild-born salmon mainly must have been offspring of salmon which themselves were wild-born the rivers did receive wild status by WGBAST (ICES, 2013a; 2014).

More detailed information on the development and most updated status of salmon stocks in potential rivers can be found in the WGBAST report.

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A.2 Fishery

This section gives detailed descriptions on how the commercial, recreational, and brood-stock salmon fisheries are currently carried out, including brief information on main fishing areas (sea, coast, rivers) and gears. If applicable and available, information on types of vessels, approximate size of fleet and number of fishermen is presented. Country-specific information has been compiled when relevant. Further descriptions of gears used in different fisheries, including extensive descriptions of gears in Sweden, Finland, Estonia, Latvia, Poland and Denmark, as well as historical gear development in the Baltic salmon fisheries, can be found in ICES (2003a).

A.2.1 Fishing areas

Catches are divided into four different fishing area categories: River (R), Coastal (C), Open sea (O) and Sea (S). Sea (S) is only used when it is not possible to separate between coast and open sea. There is no standardized way of distributing sea catches into either of the two WGBAST fishing area categories Coast (C) or Open sea (O). For the commercial fisheries, a majority of the countries divide the commercial landings on fishing area depending on which gear that has been used, where longlines and driftnets are categorised as open sea (O) and trapnets as coastal (C).

Exceptions:

- In Latvia, the distribution is depending on how the catches are reported into the official catch statistics. Here catches from vessels carrying EU logbook are categorised as open sea (O), whereas catches from vessels reporting in the national logbook system are categorised as coastal (C). Latvian vessels that are active 2 nautical miles (NM) or more off the coast are obliged to use EU logbook.
- In Lithuania, catches outside territorial water, i.e. 12 NM or more from the coast, are categorised as open sea (O). Inside this border catches are categorised as coastal (C).
- In Poland, length of the vessel defines if the catch is coastal (C) or open sea (O). Catches from vessels 10 meters or less are coastal (C) and catches from vessels longer than 10 meters are categorised as open sea (O).

Latvia and Lithuania are the only two countries directly using the actual geographical position when categorising the catches as either coastal (C) or open sea (O).

For the recreational fisheries, all countries define trolling as open sea (O) whereas catches from other gears are defined as coastal (C).

A.2.2 Commercial fisheries

In the commercial offshore (open sea) fishery, only longlines are used today for directed fishery on salmon. Driftnets, previously the most common gear in the Baltic fishery for salmon, were banned in the Baltic area 1 January 2008 according to Regulation (EC) 812/2004. From 1 January 2013, Sweden and Finland phased out their longline fishery in the Main Basin. In the commercial coastal fishery, trapnets dominate today but also anchored floating gillnets are used to some extent. Below, more detailed descriptions of gears used in the commercial fishery are given.

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Offshore longlining. The main fishing season for longlines is January and February, but some fishing takes place also during November, December, March and April. Currently, only Denmark and Poland use longlines in the offshore commercial salmon fishery. Main fishing areas for the Danish fleet are waters around Bornholm (SD 24 and 25). The main salmon fishing grounds for the Polish fleet are located N of Łeba and Ustka (SD 25) and E and NE of the Hel Peninsula (SD 26), both areas are within the Polish EEZ. Both fleets use gears of similar construction (most of Polish gears were purchased in Denmark) with the same hook size, 6/0 Mustad stainless salmon hook, 19 mm between point and shaft. The number of hooks used depends on the size of vessel, usually it varies between 700–2000. Fishers use freshly sorted sprat as bait. Hauling of the gear is usually hydraulically or, on smaller vessels, done by hand.

Floating anchored gillnets. Floating anchored gillnets are used in the Polish offshore salmon and sea trout fishery. Note that although this fishery is herein referred to as offshore, it can also be practised in coastal waters. Fishers use standard driftnets, consisting of several (up to 15) nets with a length of 28–30 m and a height of 6 m. Nets have a leaded bottom line and are anchored in one end. Usually the effort is 300–700 nets per day of fishing, depending on weather and equipment on deck. Hauling is done mechanically. In general, the mesh size is 140 mm, in accordance with regulations, but also nets with larger mesh size can be used. The legal maximum length of each set is 500 m. The typical soak time is 12–15 hours, or in case of seal damages, shorter. Anchored gillnets are mostly used during spring and autumn, but also in winter, depending on weather conditions. In Poland, 14% of the vessels operating offshore targeting salmon use both longlines and gillnets. The choice of gear for Polish vessels mostly depends on seasonal environmental (hydrological) conditions.

Floating anchored gillnets are also used for salmon fishing at the Åland Islands, Finland, where fishermen started to use them in 2008 when driftnets became banned. However, the method applied differs to the one Polish fishermen are practicing; the nets are modified (from regular 30 m long and 6–8 m high driftnets) by adding an extra lower snare to make them hanging better vertically in sea currents. Sets of three nets (about 100 m long) are used, anchored from one end (two 20 litre floats before the anchor line). More than three nets per set cannot be used because otherwise the set would sink from the pressure of sea currents. In a set, the first two nets become tighten very tense and work as a lead, while the third net flutter at the end and fish are thus entangled solely there.

The Åland fishers operate simultaneously with 7–10 sets (i.e. 20–30 nets in total) in about 50 m deep water (using about 200 m braided 6 mm anchor rope and a 6–7 kg anchor). Because of the seals present in the area, fishers have to guard the nets during the whole fishing session (about eight hours) and pick up the salmon immediately when entangled in the net (utilising floats in the upper snare as indicators).

Coastal trapnets. Coastal trapnetting for salmon is mainly conducted in Finland and Sweden, but to some extent also in Estonia and Latvia (see below). In the Baltic Sea, the trapnet fishery is mainly commercial. In Sweden, however, some recreational fishermen are fishing with trapnets as well. The main fishing season for the coastal trapnet fishery is June and July in Gulf of Bothnia, but in southern Baltic Sea the fishery takes place later in the season.

The standard gear is a floating wedge formed netpen with bottom and two valves, mesh size 80–100 mm, moored above depths of up to 50 m. The leader (up to 300 m and 3–5 m deep) usually reaches into shallow water. The construction of the gear is special for each individual fishing ground. Various types of synthetic fibres are in use,

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multifilament as well as multi-monofilament twine. Occasionally, salmon are caught in other types of coastal trapnets targeting herring, common whitefish and vendace.

With continued problems from seals predating on salmon captured in fishing gears, the use of trapnets that protect the salmon from seal predation has increased. In Gulf of Bothnia and Gulf of Finland, trapnet fisheries have been developed using new netting material that the seal cannot bite through. Also fixed fences at the entrance of the traps, preventing the seal from entering the traps, has been developed. In Sweden a new type of trap has been developed, the so called 'push-up trap', with fixed walls that protect the catch from seals.

In **Estonia** about 75% of annual catch is taken in September, October and November and nearly all caught salmon are spawners.

In **Finland** large trapnets (higher than 1.5 m) are allowed for commercial fishermen only. There are strict regulations of the fisheries regarding fishing season, effort and areas.

In **Latvia** trapnets are set near the coastline in Gulf of Riga; the highest trapnet landings are from the east coast in the Gulf. Salmon trapnet fishing at the Latvian Main Baltic coast is not common, due to the high possibility of destroyed gears in stormy weather. Different types of net material are used, mainly synthetic mono-multi-material. Mesh sizes range from 40 to 100 mm. The main fishing season is from June to September.

In **Sweden**, almost the whole commercial catch of salmon is taken in the coastal fishery using trapnets and fykenets. These fisheries are located mainly in the Gulf of Bothnia (SD 30 and 31). The main bulk of the catches are caught with so-called pontoon trapnets to protect the catch from foraging seals. The use of pontoon trapnets has increased in the last few decades, in conjunction with the increasing number of seals in the Baltic Sea. Furthermore, some salmon are occasionally caught (bycaught) in poundnets. There is no Swedish coastal fishery with stationary standard gillnets. However, in the southern part of the Swedish coast (SD 25), a minor coastal salmon fishery is conducted with an older type of gear where the fish is entangled (in contrary to how fish is caught in a trapnet).

Due to a ban for recreational fishermen to sell their catches, many recreational fishermen have applied for a commercial licence. Therefore, their trapnet catches are nowadays included in the commercial catch, and thus counted against the national quota.

River fishery. Whether it is legal to fish commercially for salmon within rivers or not varies between Baltic countries, and other differences also exist (i.e. presence of salmon rivers or not). Below follows brief country-by-country information:

- No commercial riverine fisheries exist in **Denmark, Estonia, Finland, Germany, Lithuania, Poland or Russia**.
- **Latvia**: use of trapnets is allowed in River Daugava. However, effective fishing is limited due to active shipping traffic.
- **Sweden**: commercial catches of salmon are allowed in a few rivers. All commercial river catches are from reared populations. It is mandatory to report catches from the commercial river fisheries, but information on effort is not included in the national reporting system. The commercial river

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catches are not counted against the quota since they are caught in freshwater (and not in the sea).

A.2.3 Recreational fisheries

Recreational fishing targeting salmon takes place in offshore, coastal and river areas. Landings from recreational fishing are not included in the TAC and no obligation to report catches exist. Catches are therefore estimated annually country by country through different surveys.

Recreational fishing in offshore areas is practised by trolling, mainly located to the Main Basin. Recreational fishing along coastal areas mainly occurs in SD 30 and 31 by use of traditional trapnets. Recreational river fisheries take place in wild, mixed and reared rivers, where angling by use of rod and line dominates. Traditional gears like seinenets, gillnets and trapnets are still used in some rivers. Due to stocking objectives, brood-stock fishery occurs in some reared rivers. In these reared rivers brood-stock fishery makes up a varying part of the total catch, and can in some cases be substantial. Below follows descriptions of the different recreational fisheries occurring in the Baltic Sea.

<u>Trolling fishery</u>. Recreational trolling is an increasingly common and popular fishing method to catch salmonids in the Baltic Sea. The name originated from the verb to troll, describing a fishing practice of slowly dragging a lure or bait from a moving boat. Thereby, recreational fishermen troll a number of fishing lines, baited with lures or natural bait through the water. Fishing lines are spread horizontally with help of planer boards and vertically using downriggers and stackers. Common trolling speeds vary from 1.5–3 knots. Small boats used for trolling vary between 3 and 8 meters.

Fishing grounds are usually over deeper water, and boats may venture more than 20 nautical miles offshore. Therefore, weather conditions have a strong impact on the effort, and bad weather conditions may prevent trolling boats to leave their homeports periodically. The trolling season varies between the different sea areas and depends on the feeding and spawning migration of salmon and/or seasonal closures. In the west Baltic and the Main Basin, it typically starts in late fall and ends in the middle of May. In the Åland Sea and Gulf of Bothnia, the season starts at the end of May and ends in late summer.

Trolling is not only practised in own boats by private anglers, but also by professional guiding operators. The recreational salmon fishery, including the trolling sector, supports an industry that provides jobs involved in manufacturing, sale or provision of tackle, boats, professional guide services, hotels, restaurants and more. Recent survey estimates from Germany revealed that trolling anglers spend on average € 3500 annually (Kaiser, 2016).

Recreational salmon trolling has been practised in the Baltic Sea for more than 30 years. The magnitude of this fishery varies between countries, and while in some countries trolling effort has levelled off (e.g. Sweden) it has just started developing in others (e.g. Poland and Lithuania). Despite this, catch data from trolling fisheries from individual countries are still incomplete or missing, and work on quality assurance is still ongoing. One reason is that trolling is often not included or sufficiently covered in national marine recreational fisheries surveys. More information on methods used for estimation of catches can be found in Section B.

<u>River fishery</u>. The river fishing for salmon in the Baltic region has a very long history. Until the mid-20th century, nets and weirs were used in many rivers throughout the

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area, and in some cases those gears were not phased out until in the mid-1990s. Currently the river fishery for wild salmon is entirely recreational and to a major part restricted to angling (rod and reel fishing). Different types of tackles are used, the most popular being fly and lures. Fishing is usually carried out from river banks or as wading, but in some rivers angling from boat is also possible.

The most productive wild Baltic salmon rivers are by far the Finnish and Swedish large rivers flowing into the northern Baltic Sea. The fishing season is usually from May–September, during the spawning run. The recreational fisheries in these rivers are very popular, attracting several thousands of anglers every year. Whereas salmon trolling is a highly specialized fishery, often requiring big investments in boats and other equipment, the river fishery for salmon is more easily accessible. This makes the river fishery an important component in terms of potential removal of fish from the stocks, although the introduction of regulations, e.g. catch and release and bag limits, have been implemented in many rivers. At the same time, the Finnish and Swedish river fisheries supports a local 'industry' providing jobs involved in the manufacture, sale or provision of tackle, professional guide services, hotels, restaurants and more.

The recreational river fishing for salmon in the other countries surrounding the Baltic Sea is more limited, although salmon is still being caught in Estonian, Lithuanian, Latvian and Polish rivers. The catches from rivers in these countries are, however, very small. Russia has no recreational salmon fishery in their rivers feeding into the Baltic Sea, and no Baltic salmon rivers exist in Denmark and Germany.

Other recreational fisheries. While the recreational salmon catch is largely dominated by angling (offshore trolling and in rivers) there are other types of recreational fisheries carried out in some countries. To a smaller extent passive gears such as trapnets, gillnets or longlines are being used for catching salmon, either as a target species or as a bycatch in coastal recreational fisheries. These catches are estimated to be of minor importance, in terms of impact on the stocks (i.e. removals).

A.2.4 Brood-stock fisheries

Brood-stock fisheries are aimed at collecting mature individuals for breeding purposes. As described below, those catches are often rather limited. Below follows country-by-country information about brood-stock salmon fisheries.

In **Denmark** there is no brood-stock fishery.

In **Estonia**, reared fish in the Gulf of Finland region originate in the River Kunda stock. A captive brood-stock are kept at the Põlula state-owned hatchery. The captive stock is supplemented every year by 50–60 spawners from the wild. Reared salmon released in Pärnu river (Main Basin) originate in the River Daugava river in Latvia. The caught fish are stripped from milt and eggs at the river, and whenever possible released. Those fish are not included in catch statistics. The brood-stock fishing is carried out in cooperation between Estonian Marine Institute, University of Tartu and Põlula Fish Farm.

In **Finland**, brood-stocks of five different Baltic salmon stocks (Tornionjoki, Simojoki, Iijoki, Oulujoki and Nevajoki) are kept in hatcheries. Fertilised eggs are produced at four state hatcheries (Luke). One private hatchery maintain their own Neva brood-stock. Apart from the four state hatcheries, five private hatcheries also raise salmon smolts. The private hatcheries mostly buy their eggs from the state hatcheries. Brood-stocks are kept in captivity and renewed partly or completely in 3–5 year intervals with eggs collected from brood-stock fisheries in Tornionjoki, Simojoki, Iijoki, Oulukoki and

Kymijoki (Neva stock), usually located close to the river mouth. Technicians from the state hatcheries perform the brood-stock fishing. When brood-stock fishing is conducted, usually just some tens (<100) of spawners are collected. Salmon from the brood-stock fishery have so far not been reported in the Finnish national report delivered to WGBAST.

In **Germany**, no official releases of salmon in rivers with outlet into the Baltic Sea take place, and no regular release program or brood-stock fishery exists.

In **Latvia** the artificial salmon reproduction is based on sea-run adults of wild and hatchery origin. Brood-stock fisheries are carried out in the rivers Daugava and Gauja (Gulf of Riga) and Venta (Main Baltic) in October–November. Brood-stock collection is performed by contracted fisherman who carries out a specialized fishery. All salmon catches for reproduction are indicated in the Latvian national report as fish caught for breeding purposes.

Salmon brood-stocks in **Lithuania** are collected each year from wild fish ascending spawning grounds in the Neris River basin. No hatchery origin brood-stock are used for breeding. Apart from the Neris main river, salmon is also collected from the tributaries Vilnia and Siesartis. Occasionally fishermen also catch a few individuals in the Šventoji River. Brood-stock collection is performed as a specialized fishery carried out by the Fisheries Service. All salmon catches for reproduction are indicated in the Lithuanian national reports as fish caught for breeding purposes.

In **Poland**, stocking has been based on a hatchery brood-stock of Daugava origin, supported by some spawners collected in rivers stocked with salmon (these catches are reported to WGBAST as commercial river fisheries).

In **Russia** brood-stocks are collected both from spawners kept in hatcheries and caught in rivers. For artificial production in the Neva and Narova hatcheries, brood-stocks are collected in the two respective rivers. For the Luga hatchery, a mix of spawners from the hatchery and the river is used. All salmon catches for reproduction are reported in the Russian national report as brood-stock fish.

In **Sweden**, brood-stock salmon consist of ascending spawners returning from the sea after having been released in the river as reared smolts (sea ranching). Brood-stock fish are collected annually in all rivers with compensatory releases: Luleälven, Skellefteälven, Umeälven, Ångermanälven, Indalsälven, Ljusnan and Dalälven. According to court decisions, it is the owners of the hydroelectric power stations that have the responsibility of catching brood-stock fish and performing compensatory releases of salmon smolts. To WGBAST, Sweden delivers data on brood-stock fisheries as recreational river catches.

A.2.5 International regulatory measures

The salmon fishery is regulated by both international and national management measures. International management measures adopted by IBSFC have regulated the salmon fishery in the convention area of IBSFC until the end of 2005. However, since the IBSFC was superseded by bilateral cooperation between the European Community and the Russian Federation new technical measures are developed for the Baltic salmon fishing by EU. These do not always follow strictly the recommendations made by the IBSFC but their purpose is rather to contribute to a comprehensive and consistent system of technical measures for Community waters, based on existing rules. Council Regulation (EC) No 2187/2005 laid down certain measures for the conservation of fishery resources in the waters of the Baltic Sea, the Belts and the

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Sound. Regulatory measures to be used in the Russian federation waters are not available.

The salmon fishery is also to a large extent regulated through national management measures. National regulatory measures and annual updates of these are described in detail in the WGBAST report.

Below follow a brief description of mainly international regulatory measures.

TAC. IBSFC implemented a TAC system for Baltic salmon fishery management for the first time in 1993. There are two separate management areas; one consists of the Baltic Main Basin and Gulf of Bothnia (Subdivisions 22–31) and the second of Gulf of Finland (Subdivision 32). TACs have not been agreed between EC and Russian federation. The salmon TAC agreed for Main Basin and Gulf of Bothnia, and Gulf of Finland is divided between EC countries as indicated in Table A.2.5.1 (Council regulation (EC) 2010/0247 (NLE)). Catch quotas have not been regulating the fishing pressure before year 2012, because quotas have not been fulfilled. In early and mid-1990s, however, the quotas apparently decreased offshore fishing. This decrease together with strict national regulations set for the Gulf of Bothnian coastal fisheries was the impetus to the recovery of the northern Baltic salmon stocks (Romakkaniemi *et al*., 2003). The substantial decrease in the TAC for 2012, and minor additional decreases in subsequent years, has resulted in that catch quotas again have restricted salmon fishing in some countries during the last few years.

Table A.2.5.1. Allocation of TAC between EC countries.

COUNTRY	ALLOCATION KEY (%)
Management area: Main Basin and Gulf of Bothnia (Subdivisions 22–31):	
Estonia	2.0660
Denmark	20.3287
Finland	25.3485
Germany	2.2617
Latvia	12.9300
Lithuania	1.5200
Poland	6.1670
Sweden	27.4783
Russian Federation	1.9000
Total	100
Management area: Gulf of Finland (Subdivision 32):	
Estonia	9.3000
Finland	81.4000
Russian Federation*	9.3000
Total	100

***) No agreed TAC.**

Minimum Conservation Reference Size. Minimum Conservation Reference Size (MCRS), formerly termed Minimum Landing Size before the landing obligation was implemented, of Baltic salmon is 60 cm, except for the Finnish side in SD 31 where it is 50 cm. In the commercial offshore fishery the minimum landing size is particularly important. This is due to that longlines do not have the same pronounced size selectivity as the previously used driftnets, and because younger (smaller) salmon are feeding mainly in the Main Basin (where the offshore fishery mainly occurs). There is a minimum hook size of 19 mm set for longlining in EC Baltic Sea waters. An evaluation of the effects of the minimum landing size and minimum hook size was provided by ICES (2000). However, the changes in the regulatory measures in the EC waters (Council Regulation (EC) 2187/2005) might have changed the situation, compared to in years before the enforcement of this regulation.

In river and coastal fisheries, MCRS is of little or no importance as long as smolts are protected from being captured in rivers. On the contrary, in river and coastal fisheries, this measure may decrease exploitation of the least valuable parts of the stock.

<u>Summer closure</u>. In EC Community waters there are no longer gear based summer closures. They have been replaced by restrictions on fishing for salmon and sea trout (Article 17 of the Council Regulation (EC) No 2187/2005) and they are as follows;

- The retention on board of salmon (*Salmo salar*) or sea trout (*Salmo trutta*) shall be prohibited;
    - From 1 June to 15 September in waters of Subdivisions 22 to 31;
    - From 15 June to 30 September in waters of Subdivision 32.
- The area of prohibition during the closed season shall be beyond four nautical miles measured from the baselines.
- By way of derogation from paragraph 1, the retention on board of salmon (*Salmo salar*) or sea trout (*Salmo trutta*) caught with trapnets shall be permitted.

Since 2013 only Danish and Polish longline fleets operate in SD 22–29. The previous summer closure for this fishery had a small effect, since longlining with a high CPUE is possible only during winter (from November/December to February or possibly March/April). The rule concerning a maximum number of hooks per vessel (2000 hooks) has also been taken away from the EC Council regulation, which might contribute to an increased fishing effort by longlining. As longline fishery is very labour intense, however, it is not possible to increase the number of hooks so much. In addition, some of the boats involved in longline fishery are small and they do not have capacity to use more than 2000 hooks.

<u>Driftnet ban</u>. According to Council regulation (EC) No. 812/2004 of 26.4.2004 the use of driftnets in the fishery was banned from 1 January 2008. As a consequence, the harvest rate of feeding salmon decreased to about one third from 2007 to 2008. The longline fishing then increased so that the harvest rate in offshore fishing in 2011 was probably as high as the combined harvest rate for driftnets and longlines in 2005. Thus, the ban did not affect the exploitation rate of salmon to any greater extent at first, but the exploitation rate decreased in 2012 to lower levels for other reasons (e.g. reduction in TAC). However, the measure has had other positive effects, such as reduced bycatches of seabirds and mammals.

According to Järvi (1938), Polish salmon catches from the 1930s could be dominated by small salmon (post-smolts with an average weight of about 0.5 kg). Also, Alm (1954) discussed catches of small salmon with longlines in the Baltic Sea, and suggested that this fishery should be prohibited in winter (December–March) because of the large proportion of post-smolts in catches during that time of the year. However, according to new data and expert evaluations (see working group report), the share of salmon below the Minimum Conservation Reference Size is rather low and about the same in the present offshore longline fishery as in the past driftnet fishery.

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In summary, catch of undersized salmon in the present longline fishery is most likely relatively low, although additional information is needed on how it potentially varies in time and space. Polish data from 2012–2013 indicate that 20–30% of undersized released fish was alive. However, long-term survival rate of salmon that have been released from hook and put back to sea is poorly known. Without such information, it is impossible to gauge the effects of this type of discard with respect to stock assessment and in terms of reduced catch options (i.e. by not catching the fish later in life, when it has grown larger). Therefore studies on survival would be of importance. In addition, on-board sampling is important to obtain further data on discards of undersized salmon.

The present offshore fishing of salmon (currently only Denmark and Poland) takes place in the most southern part of the Baltic Main Basin. Previously important fishing took place also in the northern Baltic Sea at the Gotland Deep, and in the Bothnian Sea and Gulf of Finland. Fishermen have reported that densities of feeding salmon have been low in northern areas, and therefore they have switched to more southern fishing areas where catches are higher. Seals and busy ship traffic also practically prevent fishing in more northern areas.

Landing obligation. Discarding refers to the practice of returning unwanted catch, dead or alive, back to the sea. During autumn 2014, the European Commission decided to introduce a discard ban for commercial fisheries, covering all species under TACs including salmon (Commission Delegated Regulation (EU) No 1396/2014 of 20 October 2014). The aim of the landing obligation is to stop the wasteful practice of discarding, promote development of more selective fishing gears and to increase the quality of catch data.

Further, the Commission Delegated Regulation (EU) No 2018/211 of 21 November 2017 established an updated discard plan concerning fisheries for salmon in the Baltic Sea, in the absence of a multiannual plan applicable to Baltic salmon stocks and fisheries. The regulation states that until December 31st 2020, (1) the landing obligation shall not apply to salmon caught with trapnets, creels/pots, fykenets and poundnets on account of high survival rates, and further (2) salmon caught without an available quota or below the minimum conservation reference size shall be released back into the sea. In addition, seal damaged salmon do not fall under the landing obligation (but should be recorded in logbooks). Knowledge of long-term survival rate and behaviour of salmon after release from trapnets is, however, limited and further investigations are needed.

An eventual future discard ban that would involve also trapnet fisheries would probably affect the coastal exploitation pattern of both salmon and other species. The estimated share of undersized salmon in coastal fisheries with traps is low (1–5%), so a discard ban will not have any major impacts on the total amount of salmon caught. However, the possibility of releasing wild salmon back into the sea, as a measure to steer the exploitation towards reared (fin-clipped) salmon, would disappear. Also, under a discard ban, trapnet fisheries targeting other species (e.g. whitefish) may have to be more strongly regulated than today, if salmon are taken as bycatch (and must be counted against the quota). But such an effect may be overcome by development of selective gears that minimizes the bycatch of salmon.

Delayed opening of the coastal salmon fishery. One important management measure beside the TAC-system has been delayed openings of the coastal fishery in the Gulf of Bothnia, a measure decided and applied on a national level in both Sweden and Finland. ICES (2007) concluded that this measure has been effective for saving a proportion of the spawning run from being harvested, and has most likely had a

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positive effect on the recovery of salmon populations in the Gulf of Bothnia. However, since 2012, when the TAC was reduced substantially, delayed opening of the fishery has probably not affected the exploitation to any larger extent as the quota has been limiting the fisheries. But as older (larger) fish and females dominate in the early part of the spawning run, whereas grilse and to a varying extent reared salmon dominate later in the season, a late opening of the fishery still save the most valuable part of the run.

Some larger river systems might hold several subpopulations ascending freshwater at different times during the season (e.g. Lind *et al.*, 2015). In such cases, focusing the exploitation on a certain time period might result in overexploitation of subpopulations migrating during that particular period.

A.2.6 Dioxin content in Baltic salmon and effects on the fishery

The maximum concentration of dioxin and dioxin-like PCB set for salmon are set out in Commission Regulation (EC) No. 1881/2006, with updates in EC 1259/2011. Further, there is also an additional regulation (EC 589/2014) stating how a control program for sampling of dioxin in fish should be set up. Overall, concentrations of dioxin and related substances tend to increase with size (sea age) of the salmon, but also vary with the fat content in different parts of the flesh (Persson et al., 2007). In general, concentrations found in Baltic salmon are above the maximum EU-limit value.

Finland, Latvia and Sweden have derogations from the regulation allowing domestic use of the salmon, providing that dietary advice is given to the public. These derogations are not time-limited. Export of wild-caught salmon to other EU countries is not permitted.

In Denmark, the following restrictions for marketing of salmon are in force from 5 December 2016:

- In ICES SD 24–26, salmon ≤5.5 kg gutted weight must be trimmed (deep skinned) before marketing. In the same subdivisions, salmon >5.5 kg and <7.9 kg can be marketed if trimmed and the ventral part of the fish is removed;
- In ICES SD 27–32, each batch of salmon >2.0 kg caught, must be analysed for dioxin before marketing. Salmon >5.5 kg (gutted weight) are not permitted to be marketed within the EU.

With these restrictions in place, it is possible to market salmon without seeking for derogations. Results from Denmark from 2013 showed high concentrations of dioxins, comparable to those in 2006. However, in 2011, deep-skinned salmon were analysed and since a general decrease in the dioxin content was then observed, these results confirm that the restrictions in practice are valid.

In Sweden, salmon caught along the coast show elevated concentrations of dioxin (Fohgelberg and Wretling, 2015). The Swedish National Food Agency (Livsmedelsverket) is responsible for sampling and analysing, and they are also obliged to provide dietary recommendations regarding dioxin and other toxic substances in fish. Their recommendations focus on minimizing consumption of fat fish from the Baltic Sea for children and women of childbearing age (current guideline is maximum 2–3 times a year) and for all others a restrictive consumption is recommended (current guideline is maximum once a week).

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In Finland the legislation requires that especially so-called vulnerable consumers (persons more susceptible to effects of environmental toxicants) are informed about the guidelines for safe use of fish.

According to the general guidelines of the Finnish Committee for Dietary Advice for food intake, fish should be eaten twice a week with changing species. As exceptions of safe consumption of fish the Finnish Food Authority has set the following guideline concerning Baltic salmon and sea trout:

- Children, young people and those at reproductive age should not eat salmon or sea trout (or herring longer than 17 cm) from the Baltic Sea more than 1–2 times a month.

In Poland, results from previous examinations have not resulted in any marketing restrictions.

A.3 Ecosystem aspects

Salmon are anadromous, i.e. they hatch in freshwater, spend one to five years in river and after this migrate for a long period to the sea, then return to freshwater to spawn. Therefore, good connectivity between the sea and rivers, as well as in the rivers, is of ultimate importance for the existence of the species. The salmon (*Salmo salar*) reproduce in rivers across the whole Baltic Sea, but the most productive rivers are found in the northern parts (Gulf of Bothnia). Salmon from different rivers (populations) are mixed in the southern Baltic during the feeding migration, but they become gradually segregated on their migration routes back to the home rivers. As an example, juveniles occupy the headwaters of the River Tornionjoki 400–500 km upstream from the sea, which is the northernmost point of the Baltic Sea drainage area. After 3–5 years growth in freshwater, the juveniles migrate to the sea, at first-feeding on insects and other invertebrates and half a year later, they shift to feed on herring and sprat in the southwestern part of the Baltic Sea proper. Salmon mature after 1–4 years growth on the feeding grounds, after which they migrate the 2000 km distance back to their natal headwater rivers for spawning.

At each stage of migration and life cycle, salmon occupies a specific niche that cannot be occupied by any other species in the ecosystem. For instance, salmon juveniles are one of the few species that can utilise fast-flowing freshwater habitats in the large northern rivers. In fact no other fish species was able to replace salmon juveniles and populate the empty rearing habitats during the deep depression in salmon abundance in the latter half of the 20th century. Salmon is adapted to uniquely utilise and link the low-productive, fast-flowing river habitat, which is a good environment for reproduction, with the pelagic sea habitat, which offers good conditions for fast growth due to the high abundance of prey species (Kulmala *et al*., 2013). This demonstrates how connectivity between river habitat, coastal transitional zone and open sea is the lifeline for Baltic salmon, and how the requirements imposed to biotic and abiotic habitat vary in time and space, depending on the life stage of the species concerned.

Today, Baltic salmon reproduce naturally in nearly 40 rivers of which 27 are considered self-sustaining wild populations. In the past, however, the number of rivers with wild Baltic salmon stocks is known to have been considerably higher, i.e. around one hundred. Damming, habitat destruction, pollution and intensive fishing have been identified as the main causes of the decline. In many rivers, hydropower exploitation has eradicated the wild salmon populations, and the production in many of these rivers is today maintained solely by breeding and releasing hatchery reared salmon. In many

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rivers in the southern Baltic, a range of problems in the freshwater environment may largely explain the current poor status of wild stocks. In many cases river damming and habitat deterioration have had devastating effects on freshwater environmental conditions. Currently, a majority of the wild salmon originates from rivers located in Sweden, Finland, Latvia and Estonia.

Salmon plays an important role in maintaining the balance in riverine foodwebs, both by harvesting invertebrate populations and also providing an important food source for other predatory species (Kulmala *et al*., 2013). The total nutrient transportation between freshwater and sea is nowadays lower than in the past due to damming and other human activities, which have decreased fish abundance, destroyed natural migration and life cycle of salmon in many spawning rivers. Salmon turns over gravel in the river bed while spawning. This bioturbation cleans river bed from, for example, organic particles the sedimentation of which is high in Baltic rivers. Spawning removes also macrophytes and invertebrates from the sediment, which may more easily be fed by river fish.

Salmon is a top fish predator in the Baltic Sea that mainly eats sprat and herring (in the south mainly sprat and towards the north increasingly herring). Thus, salmon in one sense refines various micronutrients for use of other top predators like mammals, including humans (Kulmala *et al*., 2013). Salmon muscle indeed contains plenty of polyunsaturated fatty acids, which are beneficial for human circulatory system. However, being at the top of the food chain salmon unfortunately also accumulates harmful substances, i.e. various environmental toxicants (e.g. dioxins). Salmon is a frequent prey species of grey seals, especially in the Gulf of Bothnia (e.g. Lundström *et al*., 2010). The increasing and spatially spreading Baltic Sea seal population is likely to consume more salmon, which is expected to impact the total population principally in a similar manner as fishing (Hansson *et al*., 2018).

The survival of Baltic salmon during the first year at sea (post-smolt stage) has decreased from around 30% in the mid-1990s to around 10-15% in recent years. The reasons for the decline in post-smolt survival are still unclear, but the post-smolt survival has been found to be negatively correlated with seal abundance, and positively correlated with herring recruitment in the Gulf of Bothnia (Mäntyniemi *et al*., 2012). The decline in survival seems also to be associated with changes in climatic conditions (ICES 2012b; Friedland *et al*., 2017).

Studies on Baltic salmon have found a correlation between spawning run size and spring sea surface temperatures in the Main Basin; following a cold winter and late spring, the salmon tend to arrive in smaller numbers and vice versa, a phenomena believed to be due to climate induced variation in maturation rate rather than climate effects on mortality (e.g. ICES 2012b). Cold winters have also been shown to delay the timing of the spawning run in the subsequent summer. Thus, climate variation has a rather strong impact on the population dynamics of the Baltic salmon.

On the species level, based on the IUCN criteria, Baltic salmon has been categorised as vulnerable (VU) by HELCOM. As a result of precise homing of salmon to their natal rivers, each river and even in some cases each river section, may have a genetically unique and demographically largely independent population; thus the conservation of biodiversity requires safeguarding of the genetic variation and integrity of local populations. Likewise, the development and status of single river stocks of salmon needs to be accounted for, to allow for an effective resource management.

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A.3.1 M74

The thiamine deficiency syndrome M74 is a reproductive disorder, which causes mortality among yolk-sac fry of Baltic salmon. At its worst, thiamine deficiency symptoms, such as wiggling behavior and mortalities have also been recorded among adults in brood stocks before and during the spawning period. The development of M74 is caused by a deficiency of thiamine (vitamin B1) in the salmon eggs that, in turn, is suggested to be coupled to an abundant but unbalanced fish diet with too low concentration of thiamine in relation to fat and energy content (Keinänen *et al*., 2012). The intake of thiamine for Baltic salmon in relation to energy and fat remains lowest by eating young clupeids, especially young sprat (*Sprattus sprattus*)(Keinänen *et al*., 2012). Total biomass of sprat in the Baltic main basin and salmon growth are positively correlated. Further, variation in the condition factor of prespawning salmon is explained by fluctuations in the biomass of sprat (Mikkonen *et al*., 2011). The high growth rate of salmon seems not as such be the cause, but rather the abundance of prey and its quality are responsible for M74 (Mikkonen *et al*., 2011). To inhibit M74, great variation in the size of prey stocks utilized by salmon should be avoided.

Apart from observations in hatcheries and experimental incubations, effects of the M74-syndrome was also observed as decreased parr densities in some of the wild salmon populations in 1992–1994 and also in the years 1995 and 1996, despite a large number of spawners (Karlström, 1999; Romakkaniemi et al., 2003; 2014). In the Swedish wild salmon river Ume/Vindelälven in the Gulf of Bothnia, an estimate of the egg deposition is available together with an estimate of the parr densities derived from these brood year classes. It shows that the densities of 0+ parr were low in the years 1993–1995 when the incidence of M74 was high, while parr densities were better correlated to the egg deposition in years when the incidence of M74 was low (1986–1991 and 1996–2004).

Statistics from the Swedish River Dalälven collected during 14 years (1997–2010) show that females (n = 1866) affected by M74 have a lower average weight than non-affected fish (Börjeson, 2011), and in 2007–2015 also 3% lower condition factor (Börjeson, 2015). It could be that affected M74 fish are younger than healthy females and contrary to older salmon have fed only on smaller and younger prey fish (Jacobson et al., 2018), or that they, due to their different feeding migration pattern and thus nutritional conditions, have grown less. According to Jacobson et al. (2020), salmon from the R. Dalälven generally first migrate northward before migrating to the southern parts of the Baltic Sea, whereas salmon from the more northern rivers directly head for the southern Baltic Sea. Backman (2004) found that in 1994–2001 wild salmon that ascended earlier and were larger had somewhat lower offspring M74 mortalities than fish that ascended later and were smaller. The same relationship was not found among reared salmon. This difference may be related to the differences in the feeding migration patterns. Although most Baltic salmon feed in the Baltic Proper, reared salmon at least from some stocks (e.g. R. Simojoki) remain more often feeding in the Bothnian Sea instead of migrating to the Baltic Proper (Jutila et al., 2003; Kallio-Nyberg et al., 2011; 2015). In the Bothnian Sea, salmon growth has generally been slower than in the Baltic Proper (Salminen et al., 1994; Niva, 2001; Keinänen et al., 2012).

In intra-annual comparisons among two sea-year salmon, in some years with a low M74 incidence, a negative correlation between the weight or size of females and yolk-sac fry mortality was found (Mikkonen *et al*., 2011). On the contrary, a large size (weight or length) or high condition factor of mature or prespawning female salmon was related to high yolk-sac fry mortality in years of relatively high or high M74

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incidence (Mikkonen *et al*., 2011). Although a high condition factor (CF >1.05) of prespawning salmon predicted high M74-related mortality, the high growth rate of salmon appeared not as such to be the cause of M74, but rather the abundance of prey and its high fat content (Mikkonen *et al*., 2011; Keinänen *et al*., 2012).

Evidently, because cod (*Gadus morhua*) compete with salmon for food in the Baltic Sea (Larsson, 1984), the annual growth rate and the condition factor of prespawning salmon were both inversely related to the size of the cod stock (Mikkonen *et al*., 2011). From the various stock factors of sprat and Baltic herring (*Clupea harengus membras*) in the southern Baltic Proper, the biomass of sprat had the strongest positive relationships with the growth rate and condition factor of prespawning salmon, and the total prey biomass with yolk-sac fry mortality (Backman, 2004; Mikkonen *et al*., 2011). However, sprat was the dominant prey species of salmon in that feeding area in years of high M74 incidence, and already earlier M74 had been shown to be statistically well-correlated with parameters describing the sprat stock (Karlsson *et al*., 1999).

In most cases M74 develops as a result of feeding abundantly on young fatty sprat in the Baltic Proper (Keinänen et al., 2012; 2018). However, some M74 cases may be caused by feeding abundantly and principally on young fatty herring in the Bothnian Sea, at least in years when recruitment of herring has been unusually high and prey fish have at the same time been fatty in the Bothnian Sea (Keinänen et al., unpublished). This and differences in the feeding migration patterns between and within the salmon stocks apparently explain differences in the thiamine status and annual incidence of M74 between stocks and individuals.

The M74 syndrome has unquestionably been linked to a low concentration of thiamine in unfertilized salmon eggs (Lundström *et al*., 1999; Vuorinen and Keinänen, 1999; Koski *et al*., 2001; Keinänen *et al*., 2018), and yolk-sac fry suffering from M74 can be restored in hatchery to a healthy condition by treatment with thiamine (Bylund and Lerche, 1995; Koski *et al*., 1999). The concentration of free (unphosphorylated) thiamine among the thiamine components is used as an indicator and predictor of M74 as it has appeared to correlate best with M74-related yolk-sac fry mortality (Vuorinen and Keinänen, 1999; Keinänen *et al*., 2018). A pale egg colour in M74 eggs (Börjeson *et al*., 1999; Keinänen *et al*., 2000) is a result of a low concentration of carotenoids, especially astaxanthine, having antioxidant property (Lundström *et al*., 1999; Pettersson and Lignell, 1999; Vuorinen and Keinänen, 1999). However, compared to thiamine they are not good indicators of M74 (Keinänen *et al*., 2014). An increase in the concentrations of particular organochlorines in salmon spawners ascending the River Simojoki, coincidentally with the outbreak of M74 at the start of the 1990s, was concluded to have resulted from enhanced feeding on sprat in which the concentrations of these organochlorines were high in younger age groups with the greatest fat content (Vuorinen *et al*., 2002). Bioaccumulation of specifically these organochlorines, coplanar PCBs, was most distinctly affected by the fat content of the prey and predator fish (Vuorinen *et al*., 2012). The cause of both was the same, feeding on young fatty sprat in abundance, but organochlorines are not a cause of M74 (Keinänen *et al*., 2018).

The incidence of M74 in R. Simojoki salmon in a year with a moderate incidence of M74 was connected to dietary sprat and feeding in the Baltic Proper by comparing the fatty acid composition of salmon spawners with that of feeding salmon and prey fish (sprat and herring) of the Baltic proper and Bothnian Sea (Keinänen *et al*., 2018). The fat content of sprat is on average nearly twice that of herring and it is highest in the youngest sprat (Keinänen *et al*., 2012). Both species are fattier in autumn than in spring. However, the lipid content of both species has differed between sea areas; it has been

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highest in the Bothnian Sea, average in the Baltic Proper and lowest in the (western) Gulf of Finland (Vuorinen *et al*., 2012; Keinänen *et al*., 2017). The percentage of lipid also varies more in sprat than in herring (Keinänen *et al*., 2012). The average thiamine concentration in sprat and herring (of the size preferred by salmon as prey) sampled in different seasons and years are quite similar (Keinänen *et al*., 2012; 2017), although in autumn samples, it was lower in sprat than in herring (Vuorinen *et al*., 2002). However, in both prey species the thiamine concentration by several times exceeded the nutritional guidelines on growth of salmon (see Keinänen *et al*., 2012). The thiamine concentration changed curvy–linearly with the age of both sprat and herring, being lowest in the youngest age groups [and also in the oldest herring of length >19 cm, not often included in the salmon prey (Hansson *et al*., 2001; Vuorinen *et al*., 2014)] and greatest at 6–10 years in sprat and 3–7 years in herring (Keinänen *et al*., 2012).

As thiamine has a central role in the energy metabolism, its nutritional requirement is determined by the energy density of the diet, which means the fat content of prey fish. Thus, abundance of fatty fish as food for salmon increases the requirement for thiamine. Contrary to demand, the thiamine content per unit fat and energy in the diet of salmon has been least during years and in areas where recruitment and biomass of sprat have been high (Mikkonen *et al*., 2011; Keinänen *et al*., 2012). An abundance of dietary lipid increases the content of unsaturated fatty acids, especially DHA, in the diet of salmon (Keinänen *et al*., 2017). These are susceptible to peroxidation and increase oxidative stress. Because of lipid peroxidation and the antioxidant property of thiamine, the thiamine reserves are further depleted at an increasing rate (see Keinänen *et al*., 2012; 2018) during the long spawning migration followed by a long prespawning fasting period of salmon (Ikonen, 2006). Diminished body stores do not allow adequate deposition of thiamine into developing oocytes; the development of offspring cannot be sustained until the end of the yolk-sac period, when fry start external feeding.

Because M74 is induced by the ample but unbalanced fatty food resources for salmon (primarily young sprat), the incidence of the M74 syndrome may be reduced and even prevented. The safest strategy for attaining this objective would be to ensure a large and stable cod stock in the Baltic Sea (Casini *et al*., 2009) to prey on the sprat, and possibly also by managing the sprat fishery in years when the cod stock is weak (Mikkonen *et al*., 2011; Keinänen *et al*., 2012).

In section C.1.6, a description is given of a Bayesian hierarchical model applied to the Gulf of Bothnian (GoB) monitoring data of M74 occurrence from rivers in Finland and Sweden, to obtain annual estimates of the M74-derived yolk-sac fry mortality. This information is needed to fully assess the effects of M74 on the reproductive success of spawners.

A.3.2 Effects of climate change

A concern for Baltic salmon is the long-term alterations in environmental conditions occurring as a result of climate change. Addressing the implications of climate change is particularly pertinent, considering that air temperature in this area, an important indicator of climate change, has risen faster than the global average (HELCOM, 2013). Other changes that may be relevant to Baltic salmonids during the sea phase of their life cycles are changes in sea surface temperature and ice cover. Ice cover extent and duration have decreased in the Baltic Sea over the last century (HELCOM, 2013), with ice cover extent decreasing by 20% and ice cover duration decreasing by 18 and 41 days in the Bothnian Bay and Gulf of Finland, respectively (HELCOM, 2013). Mean annual sea surface temperatures have also risen by as much as 1°C per decade between 1990

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and 2008 (HELCOM, 2013). Notably, the greatest changes in sea surface temperature have occurred and are predicted to continue to occur in the Bothnian Bay (HELCOM, 2013), which is the area where most of the production of Baltic salmon takes place. Such changes in environmental condition may exacerbate each other, a point exemplified by the fact that reduced ice cover in the Baltic has likely contributed to the steep rise in sea surface temperature (HELCOM, 2013).

Changes in freshwater systems in the Baltic area are also likely, as increasing temperatures and climate variability are expected to impact freshwater systems worldwide, particularly at northern latitudes (IPCC, 2014; ICES, 2017b). Examples of relevant changes in freshwater systems are rising water temperatures and reduced water quality resulting from increasing run-off (IPCC, 2014). Additionally, projections for the Baltic area anticipate increased rainfall in the northern portion of the region and reduced rainfall in the south, resulting in increased discharge from rivers and streams in the north and reduced discharge in the south (HELCOM, 2013).

Although limited research has been conducted regarding the effects of climate change on Baltic salmon to date, climate change is expected to influence aquatic communities in the Baltic area (e.g. Mackenzie *et al*., 2007). The effects of climate change on Atlantic salmon, though not specifically in the Baltic portion of their range, have been studied extensively (ICES, 2017b) and may serve as a reasonable first estimation of the impacts climate change may have on salmonids elsewhere. Jonsson and Jonsson's (2009) review of the effects of climate change on Atlantic salmon (and anadromous brown trout) suggests that changing water temperatures and flow may result in earlier smolt migration, later spawning, smoltification and sexual maturity at younger ages, and increased mortality. River production capacity for parr may also change as rivers' "wetted area" shrinks or swells in response to changing precipitation patterns (Sundt-Hanssen *et al*., 2018; ICES, 2017b).

Climate change may also affect Baltic salmonids indirectly, via foodweb interactions, for example. The distribution of freshwater species in the brackish Baltic Sea is likely to expand, while the distribution of marine species contracts as sea salinity decreases (Mackenzie *et al*., 2007), another potential effect of a changing precipitation regime. This in turn, could reduce cod populations, increasing sprat populations as they are released from the pressure of cod predation (HELCOM, 2013). From there, salmon predation on this unexploited food source may increase, potentially increasing the prevalence of M74 along with it.

Depending on the speed of these climate change-related effects, Baltic salmonids may adapt to their new environment (ICES, 2017b), particularly with the assistance of management strategies targeted to counteract or ease their severity. A shift towards earlier timing of smolt migration in parallel with earlier springs has been documented across the Atlantic salmon's entire natural distribution, indicating that adaptation is already occurring (Otero *et al*., 2014).

A.3.3 Ecosystem impacts of fisheries and mixed fisheries overview

In a timespan of about one century, salmon fishing has first moved from rivers and coastal areas near the river mouths to the offshore. And again, during the last two decades, the balance has shifted back to mainly coastal and river fishing. The expansion of offshore fishing coincided with the expansion of hatchery-rearing and stocking programmes of salmon juveniles for fishing. Stocking volumes have lately somewhat decreased. The current salmon fishery in the Baltic Sea probably has no or minor influence on the marine ecosystem. However, the exploitation rate on salmon may affect the riverine ecosystem through changes in species compositions. There is limited knowledge of these effects and their magnitude.

Since the 1980s the Baltic grey seal population has increased, following an earlier marked decline (Harding, *et al*. 2007; HELCOM, 2018; Natural Resources Institute Finland, https://www.luke.fi/tietoa-luonnonvaroista/riista/hylkeet/). Discarding of seal-damaged salmon occurs mainly in the coastal trapnet and gillnet fishery, but also in the offshore longline fishery. Some specimens of seals drown in trapnets. For the Gulf of Bothnia coastal fishery, seal-safe trapnets have been developed, which has lately decreased seal damages, discarding and seal deaths in gear. However, in line with the increasing grey seal population, the amount of seal damaged salmon has increased in the Main Basin longline fishery.

Salmon are caught by several gear types, and in some cases this has decreased the reliability of catch estimates of the TAC controlled salmon fishery vs. the non-controlled sea trout fishery via misreporting of salmon as sea trout. This skews species-specific estimates of fishing pressure and undermines effectiveness of management measures.

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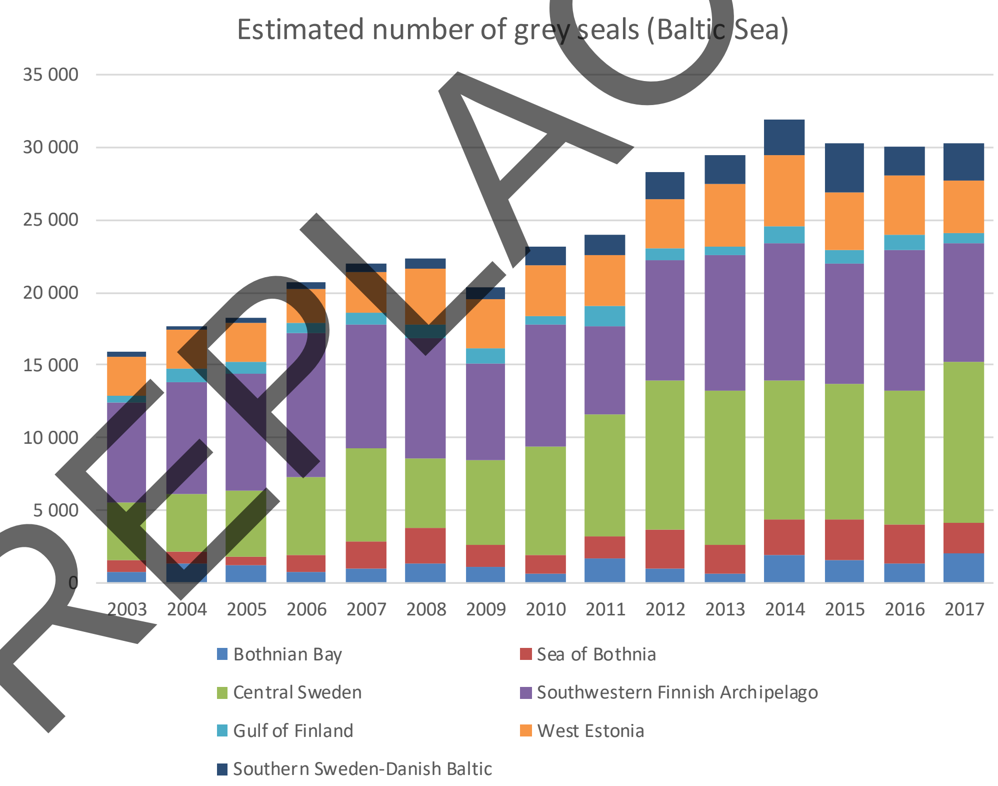

Figure A.3.3.1. Development in estimated number of grey seals in the Baltic Sea 2003-2017 (HELCOM, 2018; Natural Resources Institute Finland, https://www.luke.fi/tietoa-luonnonvaroista/riista/hylkeet/).

B. Data

The main sources of information currently used for the assessment of the wild salmon stocks can be categorized into three groups according to the place where the actual data collection is carried out:

River surveys: parr density estimates, smolt trapping, monitoring of spawning runs and river catches;

Sea surveys: catch data, fishing effort data and catch composition estimates;

Joint river and sea surveys: tagging data (tagging in rivers, recaptures from sea and river fishery).

Section C gives an overview of all the riverine and tagging data collected and used for assessment on regular basis for the different river stocks within the Baltic Sea area.

B.1 Commercial and non-commercial catch

Countries participating in the Baltic salmon fishery are asked to deliver catch data of salmon and sea trout. Catches are given by economic zone, ICES subdivision, as well as type of fishery separated by offshore, coastal and river. Catches are further classified as commercial, recreational, discard, and seal damage. Catch per unit of effort is given as weight and number of caught individuals in different gears (longline, trapnet, non-commercial catches or other). Effort is given in terms of number of fishing days each gear was deployed.

The catch statistics provided for WGBAST are mainly based on logbooks and/or sales notes. Non-commercial catches are mainly estimated by questionnaires or special issues. Area specific non-commercial catch estimates are, however, rather uncertain. In particular, estimates of catches and fishing efforts in (each) river are needed in order to better model the potential trends/changes in river fishing.

Catch tables presented in the annual WGBAST report are constructed by extracts from the WGBAST salmon catch database. Because of a delay in the delivery of data from some countries, part of the catch information is preliminary. These data are corrected the following year. Effort data are calculated separately for stocks of assessment units 1–3. Basic data for these calculations are found in the catch database, but needs to be divided into assessment units before calculations are made.

B.1.1 Collection of commercial catch data

Logbooks provide primary information on catches taken on board the vessels, where real count and weight estimates are normally difficult to obtain. The catch statistics in different countries are obtained by combination of data included in logbooks, landing declarations, first sales notes and fisheries companies catch reports. From 2005 EU type logbooks were implemented in the new member states Latvia, Estonia, Poland and Lithuania.

Collection of catch statistics by country

Denmark: The catch statistics are based on official landing reports and logbooks, combined with additional information from logbooks (e.g. type of gear for all catches and from 2007 effort for 100% of the catches), and are collected in a database at DTU Aqua. From this total catches and effort is estimated.

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Estonia: The catch statistics are based on logbooks from the offshore and coastal fisheries.

Finland: Catch statistics in the commercial fishery has been collected in logbooks from the offshore and coastal fishery.

Latvia: The Latvian salmon catch and landing statistics are based on logbooks and landing declarations from the offshore and logbooks from coastal and inland fisheries.

Lithuania: Catch statistics are based on logbook data. All data storing and processing are provided by the Fisheries Department of Ministry of Agriculture.

Poland: Commercial offshore and coastal catch statistics are based on logbooks of vessels over 8 m and on monthly reports of vessels smaller than 8 m. All raw data are sent through Regional Fisheries Inspectorates for input to the database, which is run by the VMS centre of the Ministry of Agriculture and Rural Development.

Russia: The catch statistics are based on landing reports, logbooks and direct observation of the offshore and coastal commercial fisheries. Catches could be grossly underestimated.

Sweden: Fishermen report coastal and offshore catch data to the Swedish Agency for Marine and Water Management (SwAM) either by the national electronic coastal journal or by EU logbook (paper version for vessels above 10 meters and electronically for vessels above 12 meters). SwAM is the authority responsible for the collection of commercial catch statistics both in the sea and in freshwater. However, for WGBAST purposes, commercial riverine data are compiled from a supplementary data collection programme run by the County administrative boards, instead of using the official catch data reported to SwAM by the national inland water journal.

B.1.2 Assessing catches in recreational fisheries

Commercial and recreational fisheries coexist and exploit the same stock. In the past 20 years, commercial salmon catches in the Baltic Sea have declined by nearly 80%, while recreational salmon catches have been increasing (both freshwater and marine). In contrast to commercial catch data, which rely on mandatory reporting, recreational catch data rely on estimates provided by recreational fishing surveys. While many freshwater catches are fairly well covered, either on the level of individual rivers (reporting systems, e.g. by sport fishing clubs) or in larger national surveys with a focus on recreational freshwater fishers (e.g. Finland, Sweden), available data on marine catches are patchy and for most countries missing completely.

Since 2002, European Member States (MS) are obliged to annually collect marine recreational fishery data of salmon in the Baltic Sea (EC, No 1639/2001). In 2016, the EU multiannual plan was prolonged, specifying that MS are obliged to collect numbers and weight or length for caught and released catch components of salmon and sea trout (including in freshwater) (EU, 2016/1251). There are usually three main notable challenges associated with recreational fisheries data collection: (1) there is no central registration of recreational fishers, (2) recreational catches are not documented, and (3) recreational fishers often fish in remote areas. As a result, recreational fishing surveys are complex and difficult to conduct, often requiring a combination of different "sub-surveys".

The main drivers for the collection of recreational fishery data include: collecting recreational fishing mortality for inclusion in stock assessment, designing effective controls of recreational fishing and monitoring outcomes, estimating economic value

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and social benefits to local communities, developing long-term management plans, and supporting the delivery of environmental and marine spatial planning legislation (ICES, 2015). The type of recreational fishery data needed involves information on the characteristics of the different types of recreational fisheries in a region, the size compositions for retained and released fish, and the numbers of fish retained and released per individual fishing trip.

To estimate total catches and releases, the following information is usually needed (ICES, 2015):

- Effort i.e. the total number of recreational fishers, boats, number of fishing trips or other measure of participation or fishing effort, generally estimated from a national survey.
- Catch-per-unit-effort (or catch per person or per boat, depending on the type of survey) recorded for a representative sample of fishers, boats or trips, etc., for example from on-site surveys of individual anglers or completion of catch diaries or vessel logbooks. Data are needed for the retained (harvested) catch as well as for released fish, if total fishery removals are to be estimated using data on post-release mortality.
- Demographic and avidity (frequency of fishing) data, if re-weighting of samples is needed to be more representative of the population thereby improving the accuracy of the estimate.
- Biological data on catches–size or age composition are required both for caught and released components if catch-at-size or age is needed for an assessment model. Direct on-site measurements of fish length are known to be more accurate than self-reported data.

To estimate the economic value of recreational fisheries, direct expenditure data by spend categories are also needed. This information should be collected alongside existing recreational fisheries surveys if possible, as the costs are not significantly greater. Collection of data on an annual basis is preferable, as imputations for missing years introduce uncertainty. There are strong indications that the spatial and interannual variability of fishing effort and catches is highly dynamic. Moreover, historical evidence shows that recreational fisheries may become more or less important over time, thus there is a need for time-series data to show trends.

The most cost-effective way to conduct recreational fishing surveys is having a licence system in place where licence holders can be contacted e.g. as in Denmark. Lithuania even requires mandatory catch reporting allowing for a census of recreational catch data. If no national registry is available, a screening survey is required sampling from a broad coverage frame like residential households to obtain total numbers of recreational fishers. This is usually done by means of off-site surveys (telephone, mail, online). On-site surveys like access point intercept or roving creel surveys are conducted to obtain CPUE data. Visual surveys such as aerial or camera surveys are conducted to estimate effort. A combination of several survey methods is usually required to estimate recreational catch and effort.

WGBAST recognizes the need for developing the evidence base of recreational fisheries to support decision-making and scientific advice. It is now for each country to set up national data collection schemes that provide robust and accurate estimates, especially for the marine recreational salmon fishery (i.e. mainly trolling). Regional cooperation

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and coordination is needed to develop common methods, ensuring that data collected are comparable between countries. This has to be further elaborated by ICES WGRFS and RCG Baltic, possibly in collaboration with other regional coordination groups within EU-MAP.

The following section gives a short description of the recreational salmon fisheries in each MS and provides an overview of the individual national surveys for the recreational marine salmon fisheries already in place or planned. Survey types are described in further details in 2013 report of ICES Working Group on Recreational Fisheries Surveys (WGRFS) (ICES, 2013b).

Country specific information

In **Denmark** the recreational Baltic salmon fishery is almost entirely trolling. The data collection is carried out through a combination of on-site and off-site surveys, including information from competitions and individual anglers. A recent project has been aiming at obtaining knowledge of these survey methodologies for collecting catch and effort data from the trolling fishery (www.rekrea-fisk.dk/english). The off-site part is a recall based Internet questionnaire survey targeting both passive and angling licence holders with a valid 1-year license (Sparrevohn and Storr-Paulsen, 2012). This survey runs on a biannual basis and has annually ca. 5000 respondents. Self-reporting is also made possible after each fishing trip, either by using a smartphone app or by filling in a questionnaire. The on-site part is a combination of access-point surveys, where a staff member interviews anglers returning to harbour after a fishing trip (getting catch data), and camera surveillance used in three harbours on the Island Bornholm for estimating total effort in terms of boat trips/hours at sea. The ratio between number of trips from the camera survey (census) and the self-reporting survey is used to extrapolate effort from other harbours with only the self-reporting option.

The recreational salmon fishery in **Estonia** is carried out as trolling, coastal gillnetting and river fishery. Recreational salmon and sea trout angling is allowed in rivers Narva, Purtse, Selja, Valgejõgi, Jägala, Vääna (since 2007) and Pirita. The fishery is controlled by licences and with regulations on effort in terms of length of nets (standard length of a net is 70 m). Licences are distributed annually. Estimates of river catches are from brood-stock fishery and anglers questionnaires.

In **Finland** angling in rivers and trolling at sea are two of the main recreational salmon fisheries. Recreational river catches are estimated by annual surveys and by interviews and voluntary riverside catch statistics. To obtain more accurate estimates on catches in rivers Tornionjoki and Simojoki, extensive inquiries are conducted every year among anglers who have bought a salmon fishing licence. Finnish coastal (or at sea) recreational catches are estimated by the National Survey carried out every second year. Note that in this national survey, salmon (and sea trout) catch estimates are highly uncertain because these fishers are so rare in the total population. For the missing odd years, the same sea catch estimates are assumed as in the preceding year.

In **Germany**, recreational salmon fishing occurs almost exclusively as trolling in the waters off the island of Rügen (SD 24). Since 2016, a regular survey has been established to monitor the German salmon trolling fishery. Trolling fishing effort is evaluated by boat trip counting via remote cameras in three relevant marinas on Rügen (covering ~60% of the total fishing effort) (see Kaiser, 2016 for details). Salmon trolling effort from marinas not monitored by cameras (n = 4) is extrapolated using monthly instantaneous trolling boat counts covering all marinas, and the proportions of boats that went out for fishing derived from the marinas with camera monitoring. The

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camera monitoring is complemented by random on-site interviews of anglers in four relevant marinas (including those where trolling boat trip counting was conducted) to determine catch per unit of effort. The information obtained is used for estimating catches and releases, and to collect biological catch data and socio-economic information. There is no directed recreational salmon fishery in freshwater, as there are recently and historically no rivers with relevant salmon populations along the German Baltic coast.

In **Latvia**, trolling of salmon and sea trout is currently not common; as an example, according to expert estimates only 5-10 boats were participating in this fishery in 2018. Information from recreational river fishery is available only from two rivers (Venta and Salaca) where licensed angling is organised. Recreational fishery in the coastal zone of the Baltic Sea is conducted by self-consumption fishermen. Only limited amounts of gillnets and longlines are allowed, and it is forbidden to sell any fish. Every fisher should report all fishing activities in logbooks, and those detailed data are available for the institute BIOR.

Starting from 2018, it is planned (within the EU-MAP Data Collection Programme) to estimate the Latvian recreational catches of salmon (and also sea trout, cod and eel). Recreational catches of salmon (and sea trout) will be estimated by contracting the company offering trolling trips in the sea. Catch and biological information will be collected on board and later, and applying a 'snow ball' method total landings will be estimated. Information on the licensed fishery in the rivers will be used to estimate the catches from the river recreational fishery.

In **Lithuania**, recreational fishery for salmon (and sea trout) is allowed only in designated rivers on a licence basis. Currently, new rules are in use concerning catch and release in the period from October 1st to 15th. Since 2015 recreational (anglers) sea trout catches are estimated by an online survey, a face to face interview survey, and individual interviews and catch reporting with diaries of selected anglers and experts. Catch per unit of effort data (catch per person and day) is estimated from survey data and combined with number of licences sold to anglers to calculate the total catch.

Trolling is the main recreational salmon fishery in **Poland**. Different methods are applied to monitor the composition, effort and catches of the recreational fishery. A study on the use of remote CCTV cameras for monitoring of salmon trolling fishery effort revealed that this is a cost-efficient method, providing accurate estimates of effort that helps to reduce bias in catch estimates. The method is supplemented by direct counting of trolling boats in harbours with a one month interval. As a further complement, on-site and off-site questionnaire interviews are also conducted, and trolling boats' skippers/owners are invited for filling in annual fishing logbooks. To determine catch composition and collect basic biological data, observers from the national institute (NMFRI) participate in trolling cruises targeting salmon and sea trout. On-board observations at sea, on-site interviews and data collected through CCTV cameras will serve to verify the reliability/accuracy of the catch volumes estimates. Estimated catch data from rivers is obtained from Polish Anglers Union and cooperatives having rights to fish salmon in rivers.

No recreational fishery targeting Baltic salmon is allowed in **Russia**.

Recreational salmon fishing in **Sweden** is conducted as angling in rivers and at sea (trolling), seine and gillnet fishing in some rivers and coastal trapnet fishing. In the recreational catch statistics reported to WGBAST, Swedish brood-stock fisheries in reared rivers (for hatchery production) are also included. In recent years the estimated total recreational catch has been of the same order of magnitude as the commercial

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catch, and for the recreational fishery the trend has been increasing angling and decreasing coastal trapnetting (the latter due to regulatory measures). Both for trolling at sea and angling in rivers, there is an increasing share of fishermen practicing catch and release, either voluntarily or due to regulatory measures.

Sweden does not have a general angling licence or a central register for recreational fishing, which makes it difficult to reach anglers for surveys. Recreational fishers in Sweden are generally not required to report their catches, although local exceptions exist and most salmon rivers have some kind of reporting system.

Methods for collecting recreational fishery catch statistics include:

- Censuses addressed to brood-stock fisheries.
- Voluntary reports from angling in rivers (the quality varies heavily between rivers) complemented with expert evaluations on the unreported catch in each river. Data quality is highly dependent on local culture and on how the river fishery is organized.
- Trolling catches have been estimated in 2011 and 2015. CPUE was estimated with voluntary surveys distributed in harbours and camping sites and effort by boat counts in selected harbours. The data currently reported to WGBAST is an expert evaluation based on these surveys. In 2019 a study with probability based design will be done in the southern part of Sweden. Trolling surveys will take place every second year starting from 2019.
- Subsistence fishing with traps was estimated in 2011 by a census investigation of trapnet fishermen resulting in number of traps. The number of traps was then used together with (a slightly reduced) CPUE derived from commercial fisheries in the same area. Since 2016 there are no known active recreational trapnet fisheries. The reason is that the salmon quota in recent years has been utilized before the season started for the recreational trapnet fishery.

Assessing total catch in the trolling fishery

Catch data from trolling fisheries from individual countries are still incomplete or missing, and work on quality assurance is ongoing. One reason is that trolling data collection is often not yet included or sufficiently covered in national marine recreational fisheries surveys. Therefore, the working group has yet not compiled a separate table with detailed data on national trolling catch estimates.

To account for trolling fishing mortality and to facilitate the inclusion of such catch data in the Baltic salmon stock assessment, a time-series comprising both retained and released components was developed as part of the last benchmark (ICES, 2017c). National experts (members of WGBAST) were asked to reconstruct time-series of the number of retained and released salmon caught in the recreational trolling fishery, starting from 1987, by using quantitative data from surveys (if available) and/or qualitative data from inquiries of stakeholders (e.g. experienced trolling fishers, local authorities, guiding operators and angler associations). In addition to provide a mode number of retained and released salmon for each year and area, national experts were also asked to provide a minimum and maximum value (similar to a 95% probability interval) to provide a semi-quantitative measure of uncertainty. National estimates were asked to cover the three main areas with feeding or spawning migrating salmon (i.e. SD 22–28, SD 29–31 and SD 32). Triangular probability distributions (min-modemax) per year and area collected from national experts were combined into joint medians (with 90% probability limits) using the same transformation as applied to similar expert estimates of discarding and unreporting, see working group report and Annex 4 in ICES (2016).

The total number of retained salmon includes an assumed post-release mortality rate of 25% for trolling caught and released salmon. As no post-release mortality estimates for trolling caught Atlantic or Baltic salmon in marine waters exist, the 25% mortality rate was derived from a review of studies dealing with trolling caught Pacific salmon (Parker *et al.*, 1959; Butler and Loeffel, 1972; Wertheimer, 1988; Wertheimer *et al.*, 1989; Gjernes *et al.*, 1993; Orsi *et al.*, 1993).

B.1.3 Discards and unreporting

Discards and unreporting of catches are mainly issues within the commercial fishery, but unreported catches is also important to consider in surveys aimed at assessing recreational catches. In general, data on discards, misreporting and unreporting of salmon from different fisheries in the Baltic Sea are incomplete and fragmentary. Main reasons for discard of salmon in the Baltic fisheries are seal damages on adults and bycatch of undersized young salmon. Since early 1990s, salmon discard due to seal damages occurs predominantly in the northern part of Baltic Sea, in the main distribution area of the grey seal; Gulf of Riga, Gulf of Finland and Gulf of Bothnia, but in 2010s seal damages has gradually increased in the southern Main Basin too. Bycatch of young salmon occurs in the whole Baltic Sea and in different types of fisheries, but probably mainly within pelagic sprat and herring trawling where it is likely to often remain unnoticed (e.g. ICES, 2011).

Unreporting of salmon catches is expected to occur in many types of fisheries. One type of unreporting is associated with traditional small-scale commercial fisheries, where it may occur as self-consumption, traditional direct selling from the boat, unreported discards of dead fish, etc. Unreporting may also occur in offshore fisheries for salmon or other species, including bycatch of larger salmon in large-scale trawling fisheries.

To account for presence of unreported and discarded catches, a conversion factor based on experts' opinions of these catches has been developed (ICES, 2003a; ICES, 2004b). These opinions are based on the reported knowledge presented in this stock annex and in the WGBAST report, and other background information available for each country. Coefficient factors for unreporting and discarding by country and fisheries were updated for fishing years 2001–2012 during the IBPSalmon in autumn 2012 (ICES, 2012b), and subsequently for later years (see WGBAST reports 2014–). Expert evaluations have been provided from Poland, Denmark, Sweden and Finland for all relevant fisheries of each country, respectively. These four countries cover the main salmon fisheries, and together they have caught more than 95% of the total Baltic salmon catch since early 2000s. Parameter values for the elicited priors and pooled (average) probability distributions for different conversion factors (by country and year period) are given in the working group report.

From WGBAST 2013, the average conversion factors have been calculated for all parameters separately for years before and after 2008, because of the change in relative weight between the fisheries in 2008 due to ban of driftnet fishing. In addition, Sweden and Finland banned salmon offshore fishing in the Main Basin in 2013, which further changed the relative weight between the fleets. Therefore, when relevant, the conversion factors were computed separately for fishing years from 2013 and onwards.

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Since WGBAST 2015, the average conversion factors for certain parameters have not been used in computations, since they were considered to give a too biased estimate for certain fisheries and fleets. For example, the average share of seal damaged salmon in the offshore fishery based on Swedish, Danish and Finnish data was considered to give too high estimates for discarded seal damaged salmon in the Polish offshore fishery before year 2012. The average values of the following parameters were seen inapplicable and consequently abandoned: (i) share of unreported catch in offshore fisheries, (ii) share of unreported catch in coastal fisheries, (iii) share of discarded seal damaged salmon in longline fisheries, (iv) share of discarded seal damaged salmon in driftnet fisheries and (v) share of discarded seal damaged salmon in trapnet fisheries. Therefore, instead of average values, a minimum available observed value of the parameter concerned was used for the countries and fisheries, where neither data nor expert evaluation was available.

Apart from the parameters listed above, average values were used for German, Lithuanian, Latvian, Estonian and Russian fisheries, as country-specific expert evaluations of coefficient factors were missing for those countries. However, the catches of these countries represent less than 5% of the total catch of Baltic salmon. Details on the transformation method of parameters of expert elicited triangular probability distributions into parameters of lognormal distributions is presented in ICES, 2016 (Annex 4). More information on discards and unreporting on a country-by-country basis, is presented annually in the WGBAST report.

Assumptions used in estimation of unreported catch and discards are as follows:

- In the estimation of unreported catch in the Polish salmon fishery, it was assumed that the same rate of unreporting prevails in misreported (see below) as in reported catch.
- In the estimation of seal damages and discarded undersized salmon in all fisheries, the unreporting (and misreporting in the Polish offshore fishery) was counted into the total catch, i.e. similar rates were assumed for unreported catch components as for the reported catch.
- In the Finnish salmon fisheries, seal damaged catch is derived from logbook records. These catches were raised by the relevant unreporting rates, i.e. the same unreporting rate was assumed for the seal damaged catch as for the unharmed catch. For seal damaged catch in the Swedish salmon fisheries, the same assumption is due. Here, though, the official statistics do not contain a complete quantitative measure of seal damaged catch, and instead the seal damaged catch is estimated.

Misreporting of salmon catches to varying extent probably occurs in all types of fisheries, fishery zones and countries. Typically salmon may be reported as sea trout, rainbow trout or even marine rainbow trout. Different reasons for misreporting salmon can be identified, including mistakes due, e.g. to difficulties to separate species, and deliberate actions aimed at obtaining a higher market price or to avoid fishery regulations (e.g. minimum conservation reference size or TAC). Misreporting is included in the conversion factor for unreporting of catches. Misreporting of salmon as sea trout may occur in all countries, but apart from Poland there is no indication in the data for a suspected substantial misreporting in other countries. Consequently, the suspected misreporting in the Polish offshore salmon fishery is handled separately (see WGBAST report), and estimates of the additional Polish salmon catch are included on

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top of the catch estimates generated by the general conversion factor for the offshore fishery. Estimation procedures for the rate of misreporting in the Polish fishery have developed over time depending on availability of data. Detailed information on these estimation procedures is presented in the WGBAST report.

B.2 Biological

Since 2004–2005, all EU Baltic sea countries follow the EU data collection framework (DCF) which includes collection of fishery associated data such as salmon age, length and weight composition in catches. DCF was replaced by EU-MAP in 2017. Sampling of salmon catches under EU data collection has been dealt with in the WGBAST 2005 report (ICES, 2005). The rationale of salmon sampling was described there and also in the various national programmes. The national data collection programmes mostly include different fisheries regions (offshore, coastal, river), different fisheries (commercial, angling, brood-stock), different origin (wild, reared) of fish. Only Russia provides data collection according to a state research programme.

The number of sampled and analysed fish varies between countries; mostly the national sampling programmes exceed the precision requirements of EC 1639/2001. Since the implementation of EU-MAP, for example Sweden has quit collecting catch samples as these data are not used in stock assessment, whereas other countries are still collecting catch samples. Annually at least 3–4 thousand salmon are sampled from different fisheries. Available data on age, length and weight composition of salmon catches are presented in Table B.2.1.

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Table B.2.1. Data on age, length and weight composition of salmon catches. Data available from the year indicated and onwards.

Country	Fisheries	Parameters			
		Length	Weight	Age	Sex
Denmark [1, 2]	Offshore	2002	1973	1973	-
Estonia	Coastal	2005	2005	2005	2005
Finland	Offshore [3]	1986	1986	1986	
	Coastal	1986	1986	1986	
	River	1974	1974	1974	1974
Latvia	Offshore [2]	1974	1974	1974	-
	Coastal	1978	1978	1978	1978
Lithuania	Coastal	1999	1999	1999	1999
Russia	River	Na	Na	Na	Na
Sweden [2]	Offshore [3]	2002	2002	2002	2006
	Coastal [4]	1990	1990	1990	1990
	River [4]	1991	1991	1991	1991
Poland	Offshore	2003	2003	2003	2003

1) no sampling in 2007.

2) no sampling in 2008.

3) no sampling from 2013 and onwards due to phasing out of the offshore fishery.

4) no sampling from 2018 and onwards as these data are currently not used in ICES stock assessment.

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Also other data on salmon, besides fishery associated data, is collected within the DCF/EU-MAP. This includes for example data collection in salmon index rivers. In 1999, in its 25th session, the former International Baltic Sea Fishery Commission (IBSFC) adopted a list of index rivers to be established as part of the IBSFC Salmon Action Plan. The status of wild salmon in these rivers would according to IBSFC be considered the basis for monitoring the status of wild salmon stocks. In total twelve index rivers were appointed, four in Gulf of Bothnia, five in the Main Basin and three in the Gulf of Finland. The monitoring in these rivers should consist of electrofishing, smolt trapping and counting of spawners (see Section B.3 for a description of these surveys). Since then, ICES WGBAST has evaluated the need of index rivers for stock assessment purposes and has recommended the establishment of at least one index river per assessment unit (AU), to monitor the actual importance of the fishery for the future development of river stocks in these areas, estimate properly the at-sea survival, as well as create stock–recruit functions to be able to calculate the actual potential smolt production capacity of the rivers and estimate future development of the river stocks under different exploitation scenarios. From 2018 and onwards, in total seven index rivers have been established; Tornionjoki and Simojoki (AU1), Vindelälven (AU2), Testeboån (AU3), Mörrumsån (AU4), Salaca (AU5) and Pirita (AU6).

In the established index rivers, electrofishing, smolt counting and counting of returning adults is carried out (see Section B.3 below). Part of these data is used in the assessment model (see Section C for more details), and the working group has the ambition to include additional data when it becomes available. Electrofishing data are also collected and used for assessment in all non-index rivers which are listed as wild except Piteälven. Table B.2.2 provides an outline of the data requirements by the Working Group and to what extent such data are provided by the DCF/EU-MAP. It also gives an overview of whether these data are used or not.

The amount of information available from individual rivers differs significantly by river and assessment unit. Because of the discrepancies between the amounts of information available on wild salmon in different assessment units, the uncertainties in the assessment of stock status differ significantly between assessment units.

A detailed presentation, country by country, of the data collection during the last year can be found in the WGBAST report. Also updated schemes for data collection, and future needs of inclusion of additional data collection, are presented in the annual WGBAST report.

Table B.2.2. Overview of the compatibility of data collected under the DCF/EU-MAP with the data needed for stock assessment.

Type of data	Collected under DCF/EU-MAP	Available to WG	Reviewed and evaluated by WG	Used in current assessment	Future plans	Notes
Fleet capacity	yes	yes	no	no	n	Incompatible with current assessment model
Fishing effort	yes	yes	yes	yes	n	-
Landings	yes	yes	yes	yes	n	-
Discards	yes	yes	yes	yes	n	-
Recreational fisheries	yes	yes	yes	yes	n	-
CPUE data series	yes	yes	yes	yes	n	-
Age composition (adults)	yes**	yes	yes	partly used	n	Only samples from a few rivers are used in current assessment model
Wild/reared origin (scale reading)	yes***	yes	yes	partly used	n	Only data from the Main Basin offshore fishery is used in the current assessment model
Length & weight at age (adults)	yes**	yes	yes	no	n	-
Sex ratios (adults)	yes**	yes	no	partly used	n	Not incorporated in current assessment model, river samples used
Maturity	yes**	no	no	no	n	
Economic data	yes	no*	partly used	no	n	Incompatible with current assessment model, but used for descriptions
Data processing industry	yes	no*	no	no	n	Incompatible with current assessment model
Electrofishing data	yes	yes	yes	yes	Potential increase	Length and weight at age of parr may be used to improve estimation of smolt output
Smolt trapping data	yes	yes	yes	yes	Increased use	-
Tagging data	no	yes	yes	yes	n	Mark-recapture to estimate smolt production, but tag returns from the sea phase not used from 2010 and onwards
Fish ladder data	yes	yes	yes	partly used	Increased use	-
Genetic data	yes***	yes	yes	no	Will be used	Currently used as independent information to evaluate model results, but will be used in assessment model in near future

* Not asked for by the working group.
** Required under DCF/EU-MAP, but some countries are not collecting data because of limited use for assessment
*** Only collected by some countries
n. No change.

B.3 Surveys

ICES salmon assessment is not based on sea surveys commonly used for other species. Instead, the assessment of salmon is based mainly on surveys in rivers (counting of spawners and smolts, and electrofishing surveys). Electrofishing takes place in all wild and mixed salmon rivers in The Baltic Sea, except Piteälven. Smolt counting takes place in 13 rivers. Data on adult counts is available from 13 rivers, but for various reasons not all datasets are currently used for assessment purposes. The working group has appointed the following seven Index Rivers, where all three life stages (parr, smolt and adult) are monitored annually: Tornionjoki, Simojoki, Ume/Vindelälven, Testeboån, Mörrumsån, Salaca and Pirita. See Table C.1.2.1 for more information on available survey data on a river-by-river basis.

Monitoring of parr densities in rivers are carried out by standardized electrofishing surveys in all assessment units. Fish densities are estimated by using removal fishing. The electrofishing procedure is the same today as at the beginning of the time-series. The choice of electrofishing sites in almost all rivers was done at the beginning of the time-series (mostly during the 1980s) when densities of parr were extremely low. In order to have a reasonable possibility to detect salmon parr in those years, 'best' rapids and sites were often selected. When number of sites has increased to better cover whole river systems, the selection of sites has usually been made the same way as earlier. Because of this non-random selection of monitoring sites the calculated density estimates cannot be considered as fully representative and unbiased estimates of the average parr density in a river. Instead, the density estimates serve as relative abundance indices and the possibility that the relationship between density index and

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smolt production varies from river to river must be taken into account (see Section C.1.5).

Salmon spawning runs into rivers are usually monitored in fishladders. The control of fish migration is carried out by electronic counters (usually an infrared fish counter, "Riverwatcher", Vaki Aquaculture System Ltd, Iceland), in combination with cameras which makes detection of individual species possible. DIDSON (Dual frequency IDentification SONar, http://www.soundmetrics.com/) or the similar system SIMSONAR (http://www.simsonar.com) is used in a few rivers to monitor spawning run in natural river channels. These systems use sound to produce video images of underwater areas. Identification of species is basically based on the length of the detected individuals and this sets certain limits to successful use of sonar systems to monitor salmon runs. In all fishladders and in one of the monitoring sites where sonar is used, the resulting count represents only a proportion of the total number of spawners ascending the river. This is because either the monitoring site is located in the middle- or upstream part of the river (i.e. there are reproduction areas below the monitoring site), or some fish may be able to pass the migration obstacle without using the fishladder (partial obstacle), or fish may not find the fishladder. One must take this into account when utilizing the data in the assessment, for example by using expert elicitations and/or results from tagging studies to inform the assessment model about the proportion of the total run that is monitored (see Section C.1.9).

Smolt production is monitored by partial smolt trapping and mark–recapture experiments in 1-3 rivers per assessment unit. The traps are either specially designed fykenets, classical Wolf-traps or so-called rotating screw traps (EG Solutions, Oregon, USA). A smolt trap is set up in a river as early as possible in spring and trapping continues to the end of the smolt migration season. In some years, high and late spring floods prevent early enough start of the surveys and the results from such years are not normally used in assessment. The smolt trap is emptied once or twice a day, a proportion of the catch is marked by an individual or group mark and the marked fish are then released some distance upstream the trap site. Recaptures of marked smolts are monitored at the trap. Catch and recapture data are stratified according to different time intervals, like days, or presented as annual totals. Daily water level and water temperature are also monitored as potential covariates affecting e.g. recapture rate of marked smolts. Based on this material, the catchability of the trap is estimated and the total run is assessed (see Section C.1.4). As with the monitoring sites for ascending adults, smolt traps are sometimes located upstream from the river mouths, with reproduction areas downstream, in which case monitoring does not cover the whole smolt run. Such information must be taken into account when using the data for assessment purposes (see Section C.1.5). Likewise, mortalities among smolts in e.g. power plants/turbines located downstream of the counting site must be taken into account in the assessment model.

B.4 Commercial CPUE

In the same way as biological sampling of salmon, the EU member states fisheries data collection programmes include CPUE data. The seasonal average CPUE information has been collected since 1980/1981 for Danish, Finnish, Latvian and Swedish fisheries in various combinations of subdivisions in the Main Basin, the Gulf of Bothnia and the Gulf of Finland (Table B.4.1).

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Table B.4.1. Available information on CPUE for countries, fisheries and subdivisions (LL: longlines, DN: driftnets, GN: gillnets, TN: traps).

Country	Subdivision	Offshore fisheries, gear		Coastal fisheries, gear		Period from
		LL	DN*	GN/DN	TN	
Denmark	22–25; 26–29	X	X			1983
Estonia	28–29; 32		X			1980–1988
Finland	22–31; 32	X***	X		X**	1980
Latvia	26, 28		X		X**	1980
Poland	24	X	X	X		2004
	25/26	X	X	X		2001
Russia	26		X			2000
Sweden	22–29	X***	X			1985

*** Stopped in 2008**

**** Dataseries from 2000**

***** Longline fishing in Main Basin phased out in 2013**

The CPUE is presented as number of salmon per 100 nets (driftnet), as number of salmon per 1000 hooks (longline) and number of salmon per trapnet day in coastal fisheries. From year 2001, all information available on CPUE is obtained from the WGBAST salmon catch database (see Section B.1).

B.5 Other relevant data

B.5.1 Tagging data

Tagging data are currently used for many purposes by the Working Group. Carlin tagging data have been an important information source in the assessment models for the Main Basin and the Gulf of Bothnia. Tagging data in combination with tag reporting rate have been used within the assessment of Baltic salmon in order to estimate river stock parameters as well as the exploitation rates by different fisheries (see Section C for more information). Tagging data are almost exclusively from reared salmon. Tagging of wild salmon smolts has taken place only in assessment unit 1.

Swedish tagging data constituted a major part of the data when the initial models were established in the late 1990s, but since 2001 the power companies have been responsible for most Carlin tagging, and there have been periods when the data have not been available to the WGBAST. When the database finally became available from the power companies in 2007, it turned out that the database suffered from quality problems that had arisen in the period when it had been unavailable.

The number of tag returns has become so sparse in the last few years that they update the catchability estimates little. There are various reasons for the drop in number of tag returns. Apart from the decrease in post-smolt survival, reasons include also a decrease in recapture rate due to a decline in exploitation, and the reduction in number of tagged salmon in the last few years. Another factor is the reporting rate. Some studies to estimate the reporting rate have been carried out in the Baltic Sea and their results indicate an obvious unreporting. In the assessment model, a conversion factor (which is based on expert opinions and empirical information) is used to take into account unreporting of tags (see the WGBAST report for more information). A more

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problematic issue is the possible decline in reporting rate over time. Increasing evidence suggests that the tag reporting rate of Swedish fishermen has decreased considerably but to an uncertain extent, also for tags from other countries. The reason for the decline is not clear.

The small number of tag returns is not highly critical so far in estimation of catchability values since the estimates are not year specific (each fishery based estimate covers the range of years 1987–2011). In addition the catchability of each fishery is assumed to stay rather stable through the years. However, the tag return data influence also to the annual post-smolt survival estimates, which is a key parameter in the Baltic salmon assessment framework. As the quality of the tagging data seems to have decreased considerably for the reasons mentioned above (a main problem being an assumed decline in reporting rate), tagging data from 2010 and onwards has not been used in the assessment model. Development of an alternative tagging system that could replace the Carlin tagging programme has been discussed at several occasions (e.g. ICES, 2010) but no programme has been agreed upon.

B.5.2 Analyses of catch samples

Estimates of stock proportions in catches from mixed-stock analyses (MSA), using data from DNA markers combined with smolt age information, have been presented each year by the WG since year 2000. The baseline data currently includes data for 17 microsatellite loci. On average a total of about 1500 individuals have been analysed annually, representing catches from salmon fishing areas around the Baltic Sea. Catch samples are also analysed using scale reading, which gives direct information on the composition of wild vs. reared salmon. The genetic baseline needed for estimation of stock proportions in catches has been updated continuously, and at present it includes 39 wild and reared Baltic salmon stocks.

The relative abundance of wild vs. reared salmon in the Main Basin, as determined by scale reading, is used in the assessment model (see Section C). But so far no genetic MSA results have been directly incorporated into the Baltic salmon stock assessment. Still they have served as a valuable source of independent information for various comparisons and evaluations. As an example, in 2010-2014, a series of comparisons between model predictions and empirical MSA results were carried out with respect to predicted and observed proportions of salmon from different rivers and AUs in catches from the Main Basin. Initial comparisons revealed that the life-history model at that time tended to underestimate the proportion of wild salmon significantly (ICES, 2010; 2011). Following inclusion in the life-history model of scale reading results on annual proportions of wild and reared salmon in catch samples, the expected and observed wild/reared proportions in the Main Basin became much more similar (ICES, 2012a; 2012b).

Continued MSA-monitoring of Baltic salmon catches, including further evaluations of basic assumptions and comparisons with results from the stock assessment, is expected to provide valuable information also in future, especially given the strong drop in conventional tag returns that has occurred over time. However, the necessity of actually including MSA-results directly into the stock assessment model (and how this may be done technically) has to be evaluated further.

A spatially and temporally structured Bayesian population dynamics model that tracks the migration of Baltic salmon stocks from their feeding grounds in the Baltic Sea to their natal rivers has been developed (Whitlock *et al*., 2018). The model use information about the proportions of different stocks in trap catches of fishermen at different points

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in space and time, based on samples taken from salmon in these traps, as well as information from fin-clipping data on the proportions of wild and reared fish in catches (also traps for which no genetic data are available). In the near future, the model may be used for estimation of stock-specific exploitation rates in the coastal fisheries that, in turn, can serve as input data in the current assessment model. Furthermore, the migration-catch model can be used to evaluate (by simulations) effects of changes in fishing patterns/management on the exploitation and development of wild salmon stocks. It may thus serve as an important tool for salmon management which is anticipated to become more stock-specific when a new multi-annual management plan will be decided upon (cf. European Commission, 2011, COM/2011/0470 final).

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C. Assessment: data and method

Salmon populations in Gulf of Bothnia and southern Sweden (AUs 1–4), eastern Main Basin (AU5) and Gulf of Finland (AU6) are assessed separately following different methodologies which are described under different subheadings below.

C.1 Salmon in assessment units 1–4

Model used: A Bayesian state–space model fed by multiple Bayesian data analyses

Software used: JAGS (Just Another Gibbs Sampler; Plummer, 2003) software

Model Options chosen: See later details

C.1.1 General introduction to Bayesian inference: description of the modelling approach

A Bayesian approach to statistical inference (Gelman *et al.*, 1995) has been used for the assessment of Baltic salmon in assessment units (AUs) 1–4. This approach permits a probabilistic approach to fisheries stock assessment in which uncertainties about unobserved quantities are formulated as probability distributions (McAllister and Kirkwood, 1998). It also allows a diverse range of data and expertise to be incorporated probabilistically into the stock assessment and the input to be specified in a formal and probabilistic manner.

The key idea of the Bayesian approach is to express the prior knowledge of parameters of interest (population parameters, catchability, tag reporting rate, etc.) in the form of probability distributions, and then update the knowledge of the parameters by using empirical observations. The distribution which describes the degree of knowledge before obtaining empirical observations is called the prior (probability) distribution. The distribution updated by empirical observations is called the posterior (probability) distribution which is seen as a formal compromise between the prior knowledge and information contained in observations. Generally, small amounts of data result in small updates of the prior knowledge and large amounts of data results in more substantial updates of knowledge. Posterior distributions obtained from the analysis of one dataset can be used as prior distributions in the analysis of another dataset. This way the Bayesian approach serves as a formal tool for scientific learning as the information from multiple datasets accumulates to the posterior distribution.

The probability distributions are analysed using Monte Carlo simulation methods such as Markov Chain Monte Carlo (MCMC) methods and specialized software such as JAGS and Hugin have been used to calculate the probability distributions of interest based on the statistical models and prior probability distributions. The statistics most frequently used to describe a probability distribution (i.e. mode, median, mean, 95% probability interval) are illustrated by Figure C.1.1.1.

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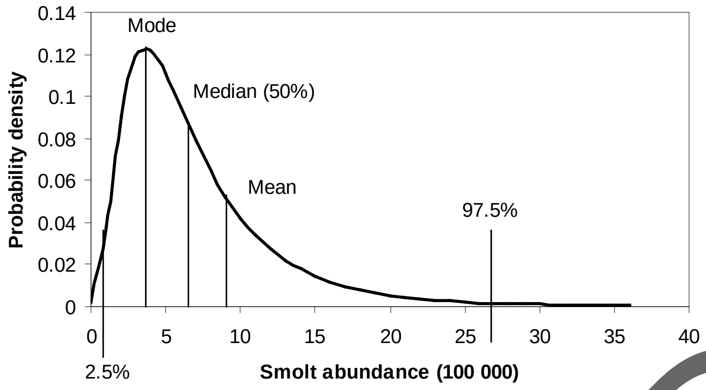

Figure C.1.1.1. Example of a posterior distribution for smolt abundance. The location of different statistics which are used to describe posterior distributions in the report are indicated by vertical lines in the figure. Most of the posterior distributions calculated by assessment models have shapes similar to the one presented here, which means that the order of mean, median and mode is the same as here: the median value lies between the most likely value (mode) and the expected value (mean).

C.1.2 Overview of the assessment method

An overview of the entire assessment model with the different submodels, data or information used within the submodels and their outputs, can be found in Figure C.1.2.1. The use of a Bayesian estimation procedure allows this type of systematic and integrative modelling approach, which is able to utilize most of the information sources available.

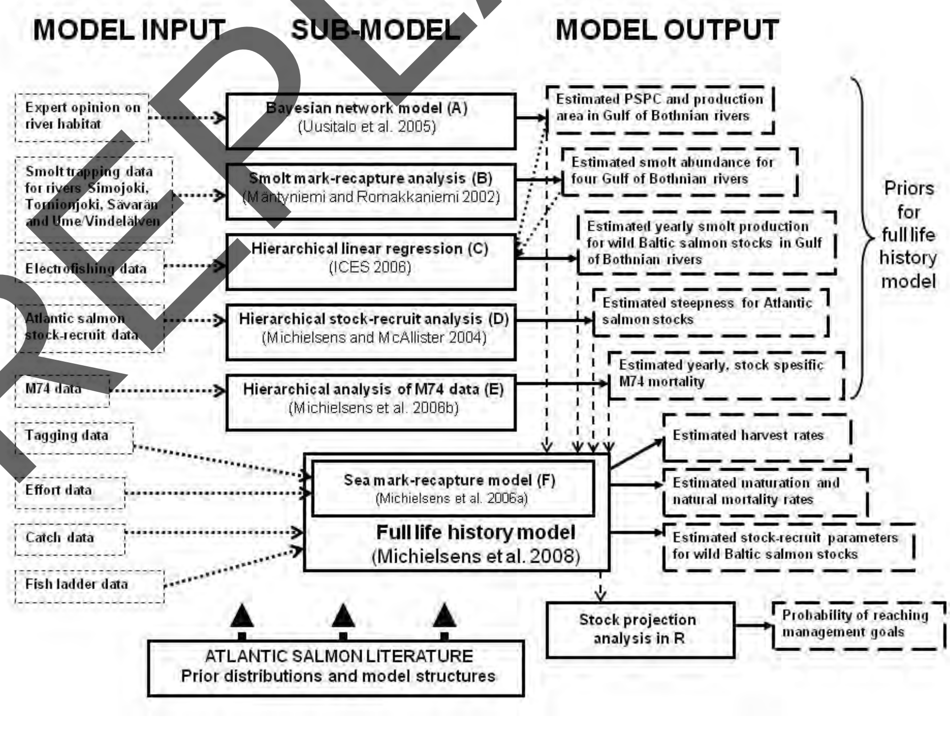

Figure C.1.2.1. Overview of the assessment methodology for Baltic salmon stocks. The results from five uppermost analyses provide informative prior probability distributions for the full life-history model. These priors become automatically updated by the information contained in the data and by the biological knowledge of the Baltic salmon life cycle used to build a full life-history model. PSPC=Potential Smolt Production Capacity.

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In 2017, a methodology benchmark was carried out to investigate alternative parameterizations of the Beverton–Holt stock–recruitment model (ICES, 2017c). Following this, the prior on Potential Smolt Production Capacity (PSPC or R_0, i.e. smolt production at the unfished demographic equilibrium) has been transferred to maximum smolt production (K, i.e. the smolt production that would be obtained with an infinite number of spawners under the Beverton–Holt model) and the prior on steepness has been replaced with a prior on maximum egg survival (α), see ICES (2017c) for details. PSPC is now calculated as a function of K, α, and eggs per recruit at the unfished equilibrium (EPR_0). These changes are reflected in the text below. In order to assess the status of the salmon stocks with respect to the reference points, the first requirement is to obtain estimates of maximum smolt production (K). A Bayesian network model (Uusitalo *et al*., 2005) has been used to obtain the prior distribution for the K of different Baltic salmon rivers. The model is based on expert opinions or judgements of the characteristics of the river environments and the corresponding salmon stocks. The resulting K estimates are used as prior probability distributions when estimating the stock–recruit relationships. Priors for some rivers have been updated in recent years.

In addition to K, the full life-history model also requires yearly smolt production estimates in order to assess the smolt production in relation to the PSPC. For the rivers Tornionjoki, Simojoki, Rickleån, Sävarån, Ume/Vindelälven, Lögdeälven, Testeboån and Mörrumsån, smolt trapping data are available that can be analysed using a mark–recapture model in order to obtain yearly smolt production estimates for these four rivers (Mäntyniemi and Romakkaniemi, 2002). For most rivers, however, only electrofishing data are available. To estimate the smolt production based on electrofishing data, the results for rivers Tornionjoki, Simojoki, Rickleån, Sävarån, Ume/Vindelälven and Lögdeälven, for which both electrofishing and smolt trapping data are available, are used within a hierarchical linear regression analysis to estimate the smolt abundance of different rivers in AU 1-3 based on parr density estimates obtained from electrofishing data (ICES, 2004a; Annex 2). In the southern Baltic, a similar approach is used for the rivers Mörrumsån, Emån and Testeboån.

In order to be able to update the historic smolt abundance estimates and predict future smolt abundances, information regarding the relationship between the number of eggs and the resulting number of smolts is needed. Within the Baltic Sea, no stock–recruit data (egg and smolt counts) as such are available. Therefore a hierarchical analysis of Atlantic salmon stock–recruit data has been undertaken in order to estimate the likely form and parameters of the stock–recruit function (Pulkkinen and Mäntyniemi, 2013).

In order to be able to use the stock–recruit function and predict future smolt abundances, a full life-history model is needed that can predict the number of spawners given a certain level of exploitation. A full life-history model requires the estimation of life-history parameters such as maturation rates, natural mortality rates and exploitation rates. In order to be able to estimate these parameters, tagging data are analysed using a mark–recapture model (Michielsens *et al*., 2006a). The results of this model are used together with the smolt abundance estimates and the priors for the stock–recruit function within a full life-history model of individual Baltic salmon stocks in order to be able to estimate the stock–recruit function parameters for individual salmon stocks, and update the smolt production and PSPC estimates of the individual salmon stocks (Michielsens *et al*., 2008).

The results of the assessment models are used to calculate the probability that 50% or 75% of the PSPC will be exceeded in a given year and to assess future probabilities of

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reaching this objective under different assumptions about future exploitation and states of nature. The probabilistic projection of the stocks beyond the year of assessment has been executed using R.

An overview of the different types of data available for the different Baltic salmon stocks can be found in Table C.1.2.1. The table indicates for which rivers the current assessment methodology is able to predict future smolt abundance to be compared to the PSPC. This estimation is based on smolt abundance estimates, spawner abundance estimates and associated stock–recruit relationships.

The following subsections discuss more in detail each of the different submodels within the assessment methodology.

Table C.1.2.1. Overview of the different types of data available for the different Baltic salmon stocks. The table also indicates for which stocks the current assessment methodology is estimating smolt abundance, spawner abundance and associated stock–recruit function. River categories: W=wild, M=mixed, R=reared.

River identification					Data									Estimates		
River	ICES subdiv	Category	Country	Index River	M74 data	Electrofishing survey	Smolt trap data	Tagging data*	Fish ladder/counter data	Broodstock fishery	River catches	Age structure**	Genetic baseline	Smolt estimates	Spawner estimates	S/R parameters
Assessment group 1: North-eastern Bothnian														x	x	x
Tornionjoki;Torneälven	31	W	FI/SE	x	x	x	x	x	x		x	x	x	x	x	x
Kalixälven	31	W	SE			x			x		x	x	x	x	x	x
Råneälven	31	W	SE			x	x		x				x	x	x	x
Simojoki	31	W	FI	x	x	x	x	x	x		x	x	x	x	x	x
Kemijoki	31	R	FI		x			x								
Iijoki	31	R	FI					x					x			
Oulujoki	31	R	FI					x	x				x			
Assessment group 2: North-western Bothn														x	x	x
Piteälven	31	W	SE						x				x	x	x	x
Åbyälven	31	W	SE			x	x		x			x	x	x	x	x
Byskeälven	31	W	SE			x			x		x	x	x	x	x	x
Kågeälven	31	W	SE			x							x	x	x	x
Rickleån	31	W	SE			x	x		x				x	x	x	x
Sävarån	31	W	SE			x	x				x	x	x	x	x	x
Ume/Vindelälven	31	W	SE	x	x	x	x	x	x	x	x	x	x	x	x	x
Öreälven	31	W	SE			x							x	x	x	x
Lögdeälven	31	W	SE			x	x						x	x	x	x
Luleälven	31	R	SE		x			x		x			x			
Skellefteälven	31	R	SE		x			x		x			x			
Assessment group 3: Bothnian Sea														x	x	x
Ljungan	30	W	SE			x		x					x	x	x	x
Testeboån	30	W	SE	x		x	x	x	x			x	x	x	x	x
Gideälven	30	R	SE					x								
Ångermanälven	30	R	SE		x			x		x			x			
Indalsälven	30	R	SE		x			x		x			x			
Dalälven	30	R	SE		x			x		x			x			
Ljunsnan	30	R	SE		x			x		x			x			
Kokemäenjoki	30	R	FI					x								
Aurajoki	29	R	FI													
Paimionjoki	29	R	FI													
Assessment group 4: Western Main Basin														x	x	x
Emån	27	W	SE			x							x	x	x	x
Mörrumsån	25	W	SE	x		x	x	x	x		x	x	x	x	x	x

* Continuous tagging of smolts, predominantly with Carlin-tags or Pittags

** Adult age data, from scale reading and/or length-based separation of grilse and multi sea winter salmon

C.1.3 Prior probability distributions for Potential Smolt Production Capacity (PSPC)

A Bayesian network model (Jensen, 2001) is used for the construction of the prior distribution for the maximum smolt production (K) for rivers Tornionjoki, Simojoki, Kalixälven, Råneälven, Åbyälven, Byskeälven, Sävarån and Ljungan. The idea is to express the knowledge of salmon scientists about K in the form of a probability distribution. In particular, the knowledge of K before obtaining any new smolt abundance data. Each expert is asked to provide their knowledge of different factors affecting K, like area suitable for production, habitat quality and mortality of smolts during downstream migration. Prior probability distributions for K are then calculated as the product of all these factors. The final prior distributions are an average over priors of all experts, which means that the diversity of different expert opinions is taken into account. Detailed description of this method can be found from Uusitalo *et al*. (2005).

Methodology

The network model summarizes the current expert knowledge of K of northern Baltic salmon rivers. The model was constructed in cooperation with salmon experts and aims to be compatible with experts' lines of reasoning rather than to describe the actual relationships of the nature in a detailed manner. Thus it describes a probabilistic justification for the expert views of salmon smolt production.

The model consists of ten variables (Figure C.1.3.1), five of which describe or reflect the external factors, physical and biological, to which salmon reproduction is exposed in the reproduction rivers (*chance of successful spawning*, *habitat quality of parr area*, *smoltification age*, *mortality during migration*, and *size of production areas*). Three variables (*parr density capacity*, *pre-smolt density capacity*, and *smolt production capacity*) describe the juvenile salmon stocks' response to the external factors. The remaining variables, *expert* and *river*, are auxiliary variables that enable handling of all the estimates in the same model. The first two variables have five discrete classes. The lowest class (i.e. very poor) is fixed to describe the situation in the poorest river in the northern Baltic Sea area, and the highest class (i.e. very good) the best salmon production river in the northern Baltic Sea. This relative scale is based on the fact that some part of the required knowledge is related to the intuitive understanding of experts who have spent most of their careers in studying these populations.

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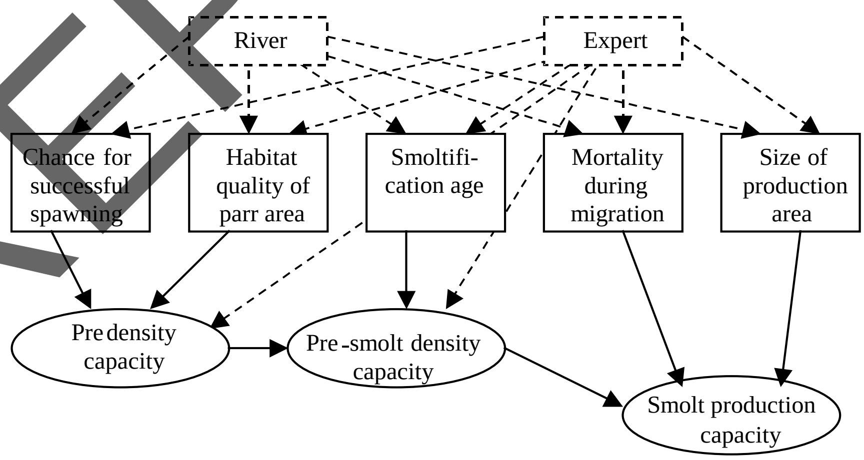

Figure C.1.3.1. Model structure. The solid rectangular nodes denote river-specific characteristics which are estimated for each river separately by each expert; the elliptical nodes denote conditional estimates on related input arcs, e.g. smolt production capacity depends on pre-smolt density capacity, mortality during migration, and the size of production area. The dashed nodes denote the auxiliary variables. The variables that are children of river are estimated separately for each river; the variables that are children of ''expert'' include separate estimates from each expert (Uusitalo *et al*., 2005).

The model outputs are discrete prior distributions for K. Discrete distributions obtained directly from the model are difficult to use as such in further analysis. Therefore suitable continuous parametric distributions have been used to approximate the shape of the exact distributions obtained from this model. Lognormal distributions with median and coefficient of variation matching with the ones of exact distributions have been used for approximation. The resulting probability distributions for the PSPC can be found in Table C.1.3.1.

K priors for rivers Mörrumsån, Emån, Kågeälven, Vindelälven and Rickleån were updated in 2015 (ICES 2015b, Annex 4), and those for Piteälven, Öreälven and Lögdeälven were updated in 2017 (ICES, 2017d). A K prior for Testebån was formulated in 2018. These priors were formulated using a mixture of empirical observations and expert opinion, for variables such as available habitat areas for different habitat quality classes; average smolt densities for the different habitat classes; natural mortality during the downstream migration, and losses to any migration obstacles such as turbines. Updates of K priors occurred for various reasons, including recolonization of areas earlier thought to be unsuitable for salmon, and restoration of river habitats.

It is important to note that these probability distributions based on expert opinions only form the prior probability distributions for the K. These priors will be updated when fitting stock–recruit models (C.1.7) to the available stock–recruit data (C.1.9), obtained by combining the smolt production estimates (C.1.4 and C.1.5) with the estimates of the marine survival (C.1.8). If the egg-to-smolt stock–recruit estimates for the Baltic salmon stocks appear to be informative, the probability density functions for K will then be substantially updated. Such an update can be expected in each assessment year as new data accumulates. The amount of annual change will depend on the amount of new data and the amount of information contained in the data.

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Table C.1.3.1. Prior probability distributions for maximum smolt production (x 1000) in different Baltic salmon rivers. The prior distributions are described in terms of their median, mode or most likely value, the 90% probability interval (PI) and the method by which prior probability distribution has been formulated. These priors will be updated when fitting the Beverton–Holt stock–recruit function to the available stock–recruit data (Section C.1.9).

	Maximum smolt production (thousands)			Method of prior
	Median	Mode	90% PI	formulation
Assessment unit 1				
1 Tornionjoki	1325	692	352-5011	1
2 Simojoki	79	40	20-310	1
3 Kalixälven	684	416	214-2188	1
4 Råneälven	55	23	12-248	1
Total assessment unit 1	2428	1704	1050-6349	
Assessment unit 2				
5 Piteälven	176	93	47-651	2
6 Åbyälven	23	12	6-89	1
7 Byskeälven	186	101	51-675	1
8 Kågeälven	54	49	32-90	1
9 Rickleån	15	13	8-28	2
10 Sävarån	7	3	1-35	1
11 Ume/Vindelälven	521	349	184-1468	2
12 Öreälven	78	56	30-203	2
13 Lögdeälven	90	66	36-227	2
Total assessment unit 2	1330	1157	781-2483	
Assessment unit 3				
14 Ljungan	7	4	2-26	1
15 Testeboån	9	7	4-22	2
Total assessment unit 3	18	14	8-40	
Assessment unit 4				
16 Emån	28	24	15-51	2
17 Mörrumsån	68	61	39-116	2
Total assessment unit 4	97	91	64-150	

Method of prior formulation for maximum smolt production
1 Elicitation of expert opinion (Uusitalo et al. 2005)
2 Elicitation of expert opinion

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C.1.4 Mark–recapture analysis of smolt trapping data

Mark–recapture experiments combined with smolt trapping have been used in nine rivers (Tornionjoki, Simojoki, Rickleån, Sävarån, Ume/Vindelälven, Lögdeälven, Testeboån, Mörrumsån and Emån). Bayesian mark–recapture model proposed by Mäntyniemi and Romakkaniemi (2002) have been used to analyse the datasets. Simplified versions of the mark–recapture model (Bayesian Petersen method) are used in cases when data have not allowed incorporation of daily variation in parameters affecting trapping success.

Data

Mark–recapture data comprises of the number of untagged fish caught by the smolt trap, the number of tagged smolts released upstream from the trap, and the number of recaptured tagged smolts. These data are stratified according to different time intervals, like days, or presented as annual totals. Environmental covariates (daily water level and water temperature data) are also included into the analysis.

Methodology

The model structure is based on biological knowledge of the behaviour of salmon smolts during their migration. For example, their tendency to form shoals is taken into account by allowing catches to be more variable than in the case of independent behaviour. Knowledge of the sampling design is also utilized in the model structure. For example, the fact that it may take several days for a tagged smolt to pass the smolt trap again after the release is accounted for by modelling the mean and variance of the swimming speed of each marking group. A vague prior distribution is used for population size when analysing smolt trapping datasets. Posterior distributions for model parameters are calculated with the help of MCMC simulation.

Key assumptions behind the model structure:

- Smolts migrate in schools (shoals) rather than independently;
- Tagged and untagged smolts have equal capture probability when passing the smolt trap.

The output of the mark–recapture analysis is a posterior probability distribution, which formally includes all the information about the smolt abundance contained in the mark–recapture data. The smolt abundance estimates will be used in combination with parr density estimates in Section C.1.5.

C.1.5 Hierarchical linear regression analysis to estimate wild smolt production of different salmon stocks

A hierarchical Bayesian model is used to describe the relationship between relative densities of salmon parr and absolute abundance of salmon smolts. Parr populations are regularly monitored and a relative index of annual parr density has been calculated in most of the Baltic salmon rivers. For some rivers (currently Tornionjoki, Simojoki, Sävarån, Ume/Vindelälven, Rickleån and Lögdeälven in AU1–2, Testeboån in AU3 and Mörrumsån and Emån in AU4) smolt abundance estimates are also available, which makes it possible to look at these rivers and learn about the relationship between parr density and corresponding wild smolt production. By using a hierarchical structure based on assumed exchangeability of stock-specific parameters, the smolt abundance for all other stocks in AU1–4 for which only parr density estimates are available is then estimated.

The core of the model is a latent dynamic linear regression model which connects relative densities of parr to smolt abundances. Information about parameter values between different rivers is transferred through hyperparameters, which are common to all rivers. Needed model inputs are prior distributions of model parameters and independent estimates of relative parr density and smolt abundance in a form of statistics of posterior distributions calculated separately from electrofishing and smolt trapping data. Wild AU1–2 stocks and AU3–4 stocks are modelled separately because of differences between AUs in central life-history traits (e.g. smolt age). See ICES (2004), Annex 2 for AU 1–2 stocks and ICES (2016) for AU 3–4 stocks.

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Data

This model requires time-series of parr abundance indices for all rivers considered, and time-series of smolt abundance estimates for as many rivers as possible. More specifically, the annual number of sampling sites electrofished and the corresponding estimated density of age 0+, 1+ and >1+ parr are needed. The number of sampling sites is used as a measure of precision of the parr density. Medians of the posterior distributions from mark–recapture analysis for smolt abundance are used as observations, and CVs of the posteriors are used as their measurement errors. In order to be able to assume that the parameters of the linear model are exchangeable between rivers, the smolt abundance of each river must be scaled down by the assumed production area of the river. The prior distributions for the smolt production area of each river are obtained from the domain experts by using the network model provided by Uusitalo *et al*. (2005) for some rivers, or updated figures where the production areas have changed since the initial elicitation was done using Uusitalo's network model (see ICES 2015b Annex 4; ICES 2017d).

Currently, parr density data from seventeen rivers in AU1–4 are used together with smolt abundance estimates from the nine rivers mentioned above. However, in connection with the launch of the new EU data collection regulation in 2017 (EU-MAP), data collection to estimate smolt abundances was intensified by including two additional smolt traps in AU 1–2 that will rotate between rivers on a 2–3 years interval. Therefore, smolt abundance estimates will be available for more rivers in the near future.

Methodology

It is assumed that a linear model can characterize the relationship between the parr density index and the smolt abundance based on the assumption that no density-dependent survival takes place in rivers of the Baltic Sea after the first summer (Figure C.1.5.1). The parameters of this linear relationship can be learned or estimated for rivers for which time-series of both parr abundance indices and smolt abundance estimates are available. It is assumed that the parameters of the linear model are not equal in all rivers, but instead they are assumed to be random draws from a distribution that characterizes the variation between rivers. In addition, production area of the river is used as an explanatory variable for the slope of the linear model in each river. The residual variance can be learned from the variance of the parameters between rivers that have the necessary data. For rivers which have only parr abundance indices, the parameters of the linear model are given prior distributions which include the between river variability of the parameters and has the expected value predicted by the production area of the river. This reflects the assumption that the parameters of the linear model are partially exchangeable between rivers. The model is described in detail in ICES (2004), Annex 2.

Key assumptions of the model:

- Parr density estimates are proportional to the true parr density.
- Survival and smoltification rates are not density-dependent after the fry stage.
- Relative selectivity of electrofishing is equal in all rivers.
- Knowing the name of the river would not help in the estimation of river-specific survival rate. This means that rivers cannot be ordered based on survival parameters by using prior information. This is the assumption of exchangeability which in turn leads to the assumption that river-specific parameters are random draws from a probability distribution describing the variation in survival between rivers.

This model produces posterior probability distributions for the annual smolt output of each river, as well as estimates of relative parr abundances, survival parameters and variation of survival parameters across rivers. The results of this analysis include all the information about smolt abundance contained in the electrofishing and smolt trapping data.

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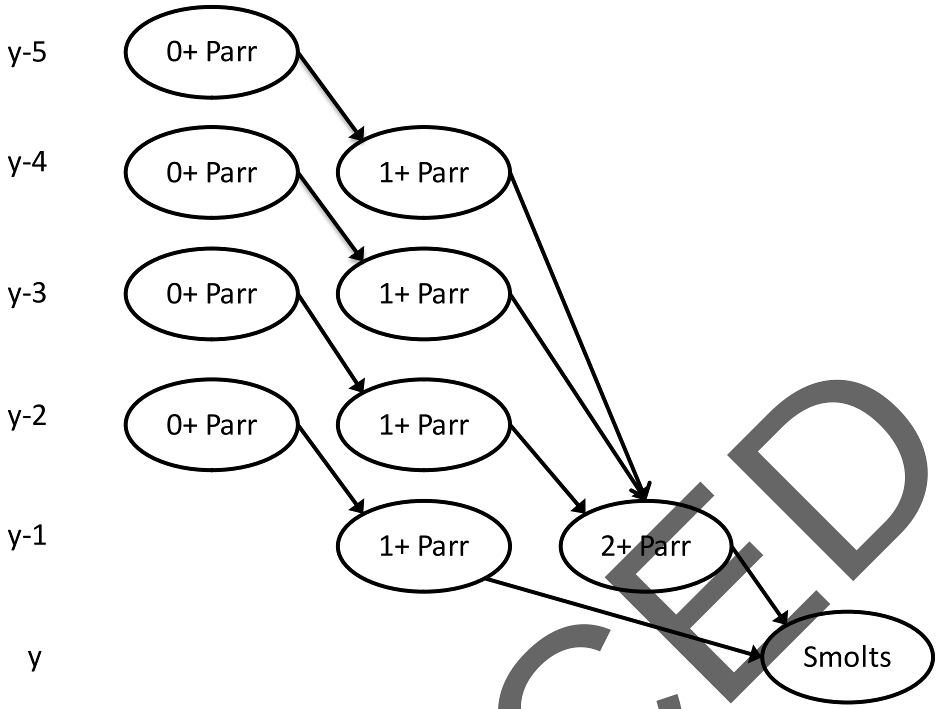

Figure C.1.5.1. A schematic diagramme illustrating the assumed dependencies when assessing the smolt abundance of year y (modified from ICES, 2004a).

In assessment units 1–2, it is assumed that parr of ages 1+ to 4+ contribute to the smolt production in any given year (Figure C.1.5.1). In the model for southern rivers (Mörrumsån, Emån and Testeboån), it is assumed that parr of ages 0+ to 3+ contribute to smolt production. For Testeboån, the estimated smolt production is adjusted to account for production that occurs downstream of the counter, as well as losses to turbine mortality after counting up to 2017.

C.1.6 Estimating M74 mortality for different wild salmon stocks

Each year, the working group updates time-series on the percentage of females (at hatcheries) affected by M74 and the percentage of total yolk-sac-fry mortality. For assessment purposes, however, we need to know the percentage of annual mortality caused by M74 among the salmon offspring. These estimates allow us to integrate M74 mortality within the population dynamics of the stock.

Data

Two different datasets have been used to calculate the mortality among alevins due to M74 mortality. The first dataset consists of data for females from the river Simojoki, Kemijoki and Tornionjoki/Torneälven stocks. For each female it is indicated if the female suffered from the M74 syndrome and the percentage of yolk-sac-fry mortality by its offspring, calculated on the basis of the proportion of alevins from each female that die. A second dataset consists of M74 information for nine Swedish salmon stocks. The dataseries indicate the number of females sampled and the number of females affected by the M74 syndrome for each year and for each stock. Updated time-series on the data mentioned above can be found in the annual WGBAST report.

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Methodology

The data are analysed using the same Bayesian hierarchical model as described by Michielsens *et al*., 2006b. The probability of eggs surviving the alevin stage depends on the probability of females being affected by M74. In case the females are not affected by M74, it is assumed that the probability of the eggs surviving the alevin stage depends on the 'normal' level of yolk-sac-fry mortality (M). If the females are affected by M74 then either all offspring die or only part of the offspring die (Figure C.1.6.1).

Because the degree of M74 mortality is assumed to differ across years and across stocks, the model calculates the average survival from M74 mortality for each stock for each year. By separating the M74 induced yolk-sac-fry mortality from the 'normal' yolk-sac-fry mortality (YSFM), the model also removes the effect of the rearing environment on the M74 mortality estimates. It is assumed that the 'normal' YSFM can differ between offspring from different females but that the variation between the 'normal' YSFM from offspring of females of the river Simojoki, Kemijoki and Tornionjoki is the same as the variation in 'normal' YSFM between different years and between different stocks. Based on this assumption it is possible to implement an hierarchical model structure and use the estimated mean 'normal' YSFM and the associated variance among females to predict the 'normal' YSFM for years and stocks for which no data exist which would allow to estimate the 'normal' YSFM. Similarly for the M74 mortality it is assumed that this mortality can differ for each female and that there is a mean M74 mortality across the different stocks for each year and a constant variation across stocks over the years. This assumption allows to use a hierarchical structure across stocks and to predict the M74 mortality for stocks for which there is no information on M74. Because the average M74 mortality across stocks is year-dependent, this methodology does not allow the prediction of future M74 mortalities.

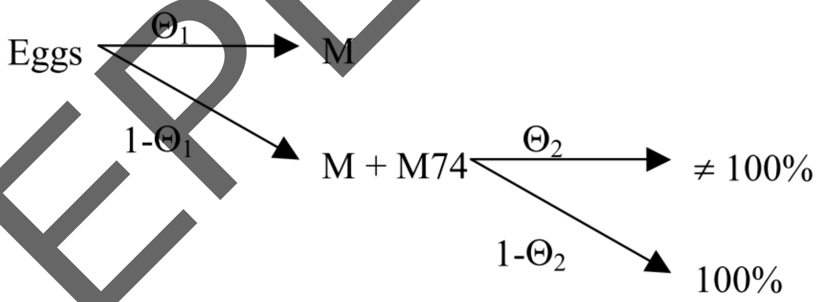

Figure C.1.6.1. Schematic illustration of the M74-model. M represents the normal yolk-sac-fry mortality (YSFM), M74 represents the mortality due to the occurrence of M74, Θ_1 is the probability that the offspring of a female will not show M74 related mortality and Θ_2 is the probability of a female of not having 100% mortality among its offspring.

C.1.7 Hierarchical analysis of Atlantic salmon stock–recruit data

A hierarchical analysis of Atlantic salmon stock–recruit data has been undertaken to come up with prior distributions for the maximum survival of eggs (α) for Baltic salmon stocks (Pulkkinen and Mäntyniemi, 2013).

Data

Until year 2008 assessment, data from river Ume/Vindel was used in the hierarchical stock–recruit analysis together with the data from other Atlantic salmon stocks (ICES, 2008a). This reflected the idea that by incorporating the stock–recruit data of at least one Baltic salmon stock, the resulting probability distribution could be used for any unsampled stock, including Baltic salmon stocks which may in certain aspects differ from Atlantic salmon stocks from outside the Baltic Sea area. However, because of this the stock–recruit parameters of river Ume/Vindel were not updated in the full life-history model and it resulted in major problems with some posterior estimates of Ume/Vindel stock–recruit parameters. As a solution to this problem, Ume/Vindel was removed from the stock–recruit analysis and it was treated similarly in the full life-history model as all the other Baltic stocks.

Consequently, the stock–recruit analysis to obtain priors for the Baltic stocks is now based on data only from Atlantic salmon stocks outside the Baltic Sea. This is deemed justified since the stock–recruit parameter values of Ume/Vindel were not extreme compared to other Atlantic salmon stocks (ICES, 2008a). It is an indication that the range of values of stock–recruit parameters obtained from outside Baltic may well cover also the range of parameter values prevailing among Baltic stocks.

Methodology

A detailed description of the model used for the hierarchical analysis of stock–recruit data can be found in Pulkkinen and Mäntyniemi (2013). Because the Beverton–Holt stock–recruit function has a much higher probability of being more suitable for Atlantic salmon than the Ricker function (Pulkkinen and Mäntyniemi, 2013), the current analysis will only be using this stock–recruit relationship.

For the Atlantic salmon stocks within the Northern Baltic Sea area (assessment units 1 to 3), it is assumed that the mean maximum survival across all Atlantic salmon stocks can be regarded as the prior distribution for the mean maximum egg survival and that the variance of the maximum survival of eggs among Atlantic salmon stocks can be used as the variance of the maximum egg survival of Northern Baltic salmon stocks. It is assumed that the mean maximum egg survival across the Southern Baltic salmon stocks (assessment unit 4) is lower than the mean maximum egg survival across the Northern Baltic salmon stocks but the variance in survival across the southern stocks is given the same prior probability distribution as for the northern stocks (Prévost *et al.*, 2003). According to the analysis, the posterior predictive distribution for the maximum survival of eggs has 0.05 as a median value and [0.01, 0.51] as a 95% PI.

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Table C.1.7.1. Mean and CV for the posterior probability distribution of the steepness for the Beverton–Holt stock–recruit function for Atlantic salmon. The posterior predictive distribution for an unsampled Atlantic salmon stock is used as a prior probability distribution for any unsampled Atlantic salmon stock in the Baltic Sea area.

	Posterior distributions	
Stock	mean	CV
Little Codroy river	0.79	0.13
Margaree river	0.66	0.19
Pollett river	0.74	0.14
Trinite river	0.79	0.13
Western Arm Brook	0.64	0.23
river Bush	0.70	0.19
river Ellidaar	0.72	0.19
river Oir	0.70	0.19
river Bec-Scie	0.67	0.19
Unknown Atlantic salmon river	0.71	0.20

C.1.8 Sea mark-recapture model for assessing the exploitation of Baltic salmon

Based on various data from fisheries and the sea and spawning migration of salmon it is possible to estimate population dynamics and harvesting of salmon from smolt to spawner. This is dealt with under this section.

Data

For the mark–recapture model, fishing effort data and tagging data have been used. The fishing effort data have been divided in separate coastal fishing efforts for stocks of assessment unit 1 to 3. The Swedish trapnet effort in Subdivision 31 has been divided between assessment units 1 and 2 with respective proportions of 45% and 55%. An overview of the number of tagged hatchery-reared and wild salmon released in rivers of assessment units 1, 2 and 3 can be found in the WGBAST report. Wild salmon have been tagged only in assessment unit 1. Because of uncertainties regarding reporting rates, data quality etc. tagging data have not been utilised in the assessment model since 2009.

For several of the parameters needed within the assessment model, basic data are fragmented and limited (e.g. tag reporting rates) or not simply not available (e.g. underreporting of catches). Instead of using the common approach of relying on expert opinions as such to extrapolate the data into parameter estimates, a more formalized approach has been used. For each parameter within the assessment model, twelve experts have been asked to provide a most likely value and a minimum and maximum value during a meeting at Bornholm in 2003 (ICES, 2003a). These expert opinions were based on data obtained from previous studies done, on literature, on the experts' experience or were subjective expert estimations in case no other information was available. Preliminary analyses, used for the formulation of prior probability distributions, included among others information from the brood-stock fisheries, double tagging experiments, etc. Care has been taken to assure that the prior distributions were not based on data used within the mark–recapture model in order to avoid using the same data twice and thus rendering the results too informative. In general, these preliminary analyses gave often only a first indication of the model parameters but expert opinion needed to be used for example to extrapolate it to the entire Baltic Sea, or to other fisheries, etc.

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The use of multiple experts resulted in multiple priors for the different model parameters. Model parameters such as the reporting rates of tags are dependent on the country. As such, the probability distributions for each country have been weighted by the country's contribution to catches of salmon and arithmetic pooling of the priors has been applied (Genest and Zidek, 1986; Spiegelhalter *et al.*, 2004). For other priors each expert is assumed to have equal expertise, arithmetic pooling without weighting of the priors has been applied. A description of the different model parameters and their prior probability distribution has been provided by ICES (2005).

The expert elicitation was carried out for the first time in 2003 (ICES 2003a). At that time the experts from whom opinions were elicited were mainly members of the WGBAST. However, because of the changes in the Baltic salmon fishery the WG saw appropriate to repeat the expert judgement in autumn 2012 (ICES, 2012b). The biological parameters were excluded and the focus was solely on tag reporting, unreporting of catch and effort and rate of discards in different fisheries. This time a wider group of people including persons working with fisheries inspection and in fisheries statistics departments and also some fishermen were interviewed. The new expert judgements and resulting conversion factors from 2012 have been applied from year 2004 in the assessment. The results from the 2003 elicitation are used for years 1987–2003. Summary of the uncertainties associated to tag reporting and fishery can be found in the WGBAST report.

Methodology

The mark–recapture model is run within the full life-history model (Section C.1.9 below) and therefore separation of the descriptions of these two models is somewhat artificial. A state–space formulation is adopted to account for uncertainties in system dynamics and the observation process. The population dynamics model used within the mark–recapture analysis is age-structured and different fisheries are assumed to take place sequentially over time (Figure C.1.8.1). A detailed description of the model can be found in Michielsens *et al.*, 2006a. The main difference between the model used by WGBAST and the one presented in this paper is that for the working group the model has been expanded to include assessment units 1 to 4 instead of only assessment unit 1. The main assumptions about the salmon stocks in the model are:

- The maturation rate for wild grilse is lower than that of the hatchery-reared grilse (Kallio-Nyberg and Koljonen, 1997; Jutila *et al.*, 2003).
- The post-smolt mortality rate of hatchery-reared fish is considered to be higher than that of wild fish (Olla *et al.*, 1998; Brown and Laland, 2001). The difference in post-smolt mortality rates between wild and reared salmon is modelled with an effect term which states that the instantaneous post-smolt mortality for reared salmon is the mortality of wild salmon times the effect term. The year specific effect terms for wild salmon are sampled from a distribution whose mean is the mean wild post-smolt mortality rate over the preceding 4 years.
- The instantaneous natural mortality rate for adult salmon is allowed to differ between wild and reared salmon, but within both groups it is assumed to be constant over the years (except the mortality caused by seals along the coast, see below).
- On the coastal spawning migration for salmon from assessment units 1-3, seals are assumed to capture salmon (except post-smolts) at the entrance or outside the trapnets; this extra source of natural mortality is assumed to

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have increased proportionally to the increase of the Baltic seal population since 1989. This increase is incorporated by a coefficient which is given value=1 for year 1989 and which increases proportionally to the development of seal abundance, until 2015, when the seal mortality coefficient is assumed to level off at a value of ~10.

- It is assumed that all adults die after spawning.

The main assumptions about the fishery in the mark–recapture model are:

- Stocks belonging to the same assessment unit experience the same harvest rates.
- Harvest rates between salmon stocks of assessment unit 1 to 4 mainly differ in the coastal fisheries and it is assumed that no coastal fishery exploits the salmon of assessment unit 4.
- The catchability coefficients for the different offshore and coastal fisheries are assumed constant over the years.

For each year, the model estimates different fishing mortality rates depending on the fishery (offshore driftnet, offshore longline, coastal driftnet, trapnet and gillnet and river fishery), depending on the age of the fish, and depending on whether it is a wild or hatchery-reared fish.

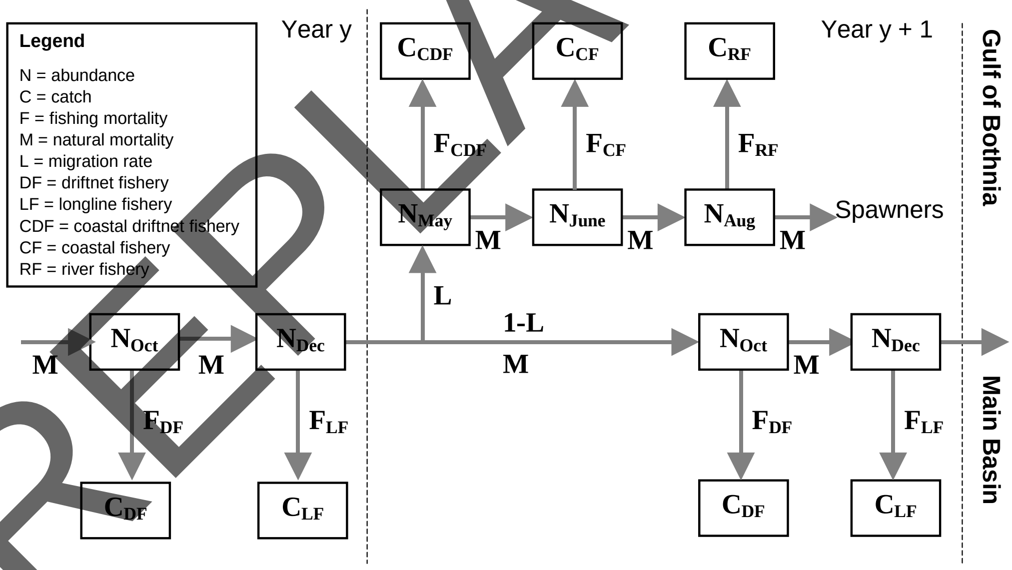

Figure C.1.8.1. Schematic presentation of the mark–recapture model for Baltic salmon. The offshore driftnet and longline fisheries in the Baltic Main Basin are assumed to take place in October and December, respectively. During the migration to the spawning grounds, the salmon can be intercepted by the coastal driftnet fishery in May, the trapnet and gillnet fisheries in June and the river fishery in August (Michielsens *et al.*, 2006a).

C.1.9 Full life-history model of different wild Baltic salmon stocks

Spawner abundance estimates have been obtained by using the wild smolt abundance estimates of different rivers (Section C.1.5) and assuming similar population dynamics as in the mark–recapture model (Section C.1.8; Michielsens *et al.*, 2006a; Michielsens *et al.*, 2008). By linking the derived egg abundance estimates with the wild smolt abundance four years (in the case of Gulf of Bothnia stocks, assessment units 1–3) or

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three years (in case of assessment unit 4 stocks and Testeboån) later, it is possible to estimate stock–recruit parameters. The resulting stock–recruit function makes the loop between salmon generations and the estimates of abundance and survival parameters become updated across the time-series. The resulting posterior distributions are then used to assess the stock status and to predict abundance into the future.

Data

Both the total number of wild smolts and numbers of released hatchery-reared smolts are used as inputs into the model. The model is also fitted to offshore, coastal and river catches. Because of suspected substantial misreporting of salmon as sea trout in the Polish offshore fishery, Polish catches have been calculated based on biological information on species composition in the area (see further explanations in Section B and in the working group report). The Swedish trapnetting effort has been approximated by using Swedish catch data and Finnish catch per unit of effort for trapnetting, assuming 80% fishing efficiency for Swedish fishermen compared to the Finnish ones. Also, Swedish recreational trapnet fishery is assumed to have 80% of the efficiency of the Swedish commercial trapnet fishery. The number of salmon mauled by seals (discards) in coastal trapnets of the Gulf of Bothnia is calculated based on reports of Finnish fishermen.

Because assessment units 5 and 6 have not yet been included in the model, model-predicted catches are raised by the proportions of smolts produced in these assessment units compared with the total smolt production of all units. In addition, the model also uses the data on the spawner counts in the rivers Ume/Vindelälven, Kalixälven, Tornionjoki/Torneälven, Simojoki and Piteälven and data on proportion of MSW (multi-sea-winter) spawners encountered in the rivers Tornionjoki, Kalixälven, Byskeälven, Ume/Vindelälven, Öreälven and Piteälven. The model also utilizes trap catches and the associated mark–recapture experiments of reared spawners in the rivers Dalälven in 2004–2011 and Luleälven in 1996, 1997 and 2001.

Data available about the relative occurrence of wild vs. reared salmon in catches is utilized from the river Tornionjoki (all years) and from offshore fishery (years 1996, 1998, 2001–). The data from the offshore fishery consists of the samples used for the genetic and scale reading analyses (see Section B), supplemented with some samples left outside the current genetic analyses.

By linking the wild spawner abundance produced from the yearly smolt production, with the smolt production four years (three years for AU4) after the year of spawning, it is possible to obtain stock–recruit information for wild salmon stocks. For each stock, the estimated abundances of spawners of different ages are multiplied with corresponding sex ratios and fecundity values (eggs/female) in order to estimate the total number of eggs deposited in each river in each year. Since the 2018 assessment, a different (and annually changing) sex ratio for multi-sea-winter salmon is now applied to Ume/Vindelälven, compared with that for other rivers (Table C.1.9.1). The resulting number of eggs has been corrected for the effect of M74 by multiplying the estimated number of eggs with the percentage of yolk-sac-fry mortality due to the occurrence of M74 (Section C.1.6). In case no M74 data have been available for certain river stocks, the predictions of M74 related yolk-sac-fry mortality for unknown stocks are used.

Methodology

The population dynamics for the total abundance of salmon is expressed by similar equations as the population dynamics for the abundance of tagged salmon

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(Michielsens *et al*., 2006a). In order to estimate salmon catches, the tag reporting rates within the catch equation for tagged salmon have been replaced by the catch reporting rates. The main model outputs are the estimated stock–recruit parameters, i.e. the maximum egg survival parameter and the PSPCs.

The model simultaneously models the tagged salmon population and the total salmon population. For tagged salmon, the population equations account for tagging induced mortality, tag shedding and underreporting of tagged salmon catches. Based on the tagging data, the model is able to estimate maturation rates, natural mortality rates, and harvest rates. These estimates are then used to model the total salmon population based on the number of wild and released hatchery-reared salmon smolts. In order to estimate the coastal and river catches, the corresponding equations account for possible underreporting of the salmon catches. The probability distributions for the wild smolt abundance will be used as priors until the year 1995 (AU1–3) or 1994 (AU4 and Testeboån), after which the model is able to calculate the smolt abundance using the estimated number of spawners and the stock–recruit parameters. From that year onwards, the model can be fitted to the smolt abundance estimates instead of using them as priors. The entire model has thus been fitted to tagging data, catch data, catch composition data, data on the composition and counts of the spawning run, and data on smolt and parr abundance.

The prior probability distributions for the maximum smolt production for the different river stocks have been obtained by Uusitalo *et al*., 2005 (Section C.1.3), based on expert opinions, or derived from updated expert opinions as described in ICES (2015b, 2017d). The prior distribution for the maximum egg survival in each river has been derived by the hierarchical model described in Section C.1.7. These priors become updated by the full life-history model taking into account all available data. PSPC is then calculated as a function of α, K and eggs per recruit under unfished conditions.

Fishladder counts of spawners in rivers Kalixälven, Tornionjoki/Torneälven and Simojoki have been fitted with the amount of spawners ascending to the river. The probability for a spawner to be observed in the counter has been allowed to vary between years around a common mean. The model has been fitted also to the fishladder counts of spawners for rivers Ume/Vindelälven and Piteälven. Here, the ladder counts are assumed to indicate the maximum limit for the number of spawners, because river fishing harvests salmon that pass the ladder. A separate parameter defines the success of ascending fish to find the fishladder. For Ume/Vindelälven, this parameter is given a prior distribution based on the results of tagging studies carried out in the river. Since 2018’s assessment, extra mortality is applied to migrating fish after counting for the years 1995, 2004 and 2014 onwards in Ume/Vindelälven (Table C.1.9.1). This change is intended to better describe the current situation in this river, with very small numbers of females spawning in recent years.

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Table C.1.9.1. Female proportion among MSW salmon in Vindelälven, and assumed survival after counting.

Year	Female proportion, multi sea winter	Survival after counting (%) Median	90% PI
1987	0.43	99.9	99.8-99.9
1988	0.68	99.9	99.8-99.9
1989	0.58	99.9	99.8-99.9
1990	0.58	99.9	99.8-99.9
1991	0.8	99.9	99.8-99.9
1992	0.81	99.9	99.8-99.9
1993	0.57	99.9	99.8-99.9
1994	0.71	99.9	99.8-99.9
1995	0.35	50.0	33.0-67.2
1996	0.72	99.9	99.8-99.9
1997	0.66	99.9	99.8-99.9
1998	0.43	99.9	99.8-99.9
1999	0.47	99.9	99.8-99.9
2000	0.48	99.9	99.8-99.9
2001	0.51	99.9	99.8-99.9
2002	0.61	99.9	99.8-99.9
2003	0.58	99.9	99.8-99.9
2004	0.33	50.0	33.0-67.2
2005	0.57	99.9	99.8-99.9
2006	0.61	99.9	99.8-99.9
2007	0.46	99.9	99.8-99.9
2008	0.64	99.9	99.8-99.9
2009	0.64	99.9	99.8-99.9
2010	0.5	99.9	99.8-99.9
2011	0.36	99.9	99.8-99.9
2012	0.28	99.9	99.8-99.9
2013	0.48	99.9	99.8-99.9
2014	0.32	50.0	33.0-67.2
2015	0.18	78.6	64.4-89.2
2016	0.58	68.4	48.8-84.4
2017	0.32	27.0	12.3-46.4
2018	0.26	50.0	33.0-67.2
2019	0.33	NA	NA

To increase information on survival and abundance of reared salmon, data from previous mark-recapture experiments in Luleälven (1996, 1997 and 2001) and Dalälven (2004–2011) are used as input data in the assessment model. In tagging studies carried out in Luleälven, it was assumed that all salmon had reached the uppermost part of the river by the time of mark–recapture experiments. It was further assumed that the salmon were moving around randomly in the area and that all individuals had the same probability to enter the trap. The experiment period differed between the years when tagging studies were performed, and thus the data were standardized with the period length (in days) since the possibility for a fish to enter the trap increases as the number of experiment days increases. A small observation model was fitted for the standardized mark–recapture experiment data to estimate the catchability of the trap. The data on total number of salmon caught by the trap was also standardized, and together with the mark–recapture data it provided an estimate of the total number of salmon surviving to the uppermost part of the river during the experimental years. This information has been fitted with the model predicted abundances of reared fish in the Luleälven within the full life-history model.

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Data on river Dalälven surviving salmon has been modelled similarly as in Luleälven case, but in Dalälven there was no need to standardize the data with the number of experiment days. In the river Dalälven case, the prior distribution was given for the mean catchability of the trap and its variation over the years based on the information from continuous mark–recapture studies. This means that for river Dalälven, the original mark–recapture data are not included in the model (as is the case for Luleälven) since the prior distribution is informative enough in itself.

In addition to data/information presented above, the model is fitted to time-series on the proportion of wild vs. hatchery-reared spawners in river catches from Tornionjoki/Torneälven. The model is also fitted to time-series of wild/reared proportions in catch samples from the offshore fishery. Because the offshore catch samples clearly consist of separate samples in time and space within each year, the wild/reared proportions are first analysed on annual basis using a hierarchical Bayesian model which allows estimation of true proportions from samples (Samu Mäntyniemi, unpublished). The results of this submodel are then fed in the full life-history model as priors.

Estimation of post-smolt mortality. The first year at sea (post-smolt stage) is known to be critical for salmon because a large proportion of the marine mortality occurs within this period. Virtually no data exist about this stage of salmon's life, and therefore it is largely unknown what the exact processes are in this period and how they affect survival of salmon. Instead, data exist just before the period (smolt production estimates for wild salmon and stocking statistics for reared salmon) and also right after the period when salmon recruit to the fisheries and grilse mature. The post-smolt survival is year (i.e. smolt cohort) specific and the parameter aggregates all information about the total mortality within the post-smolt period. The parameter estimate is basically directly calculated from the difference in abundance estimates just before and right after the period. It should be noted that the abundance estimate after the post-smolt stage is derived from and strongly affected by all the accumulating information about the cohort specific abundance at later ages (as discussed above; catches, tag recaptures, spawner counts, etc.).

Estimation of harvest rates. Harvest rates depend on the model estimated catchabilities and effort input with equation

$$HR_{a,y} = 1 - \exp(-q_a \cdot E_y),$$

where q_a is the catchability of salmon of sea age a and E_y is the effort in the fishery in year y. Furthermore, catchabilites are estimated separately for wild and reared salmon, and thus also harvest rates differ for those groups. There are 4 sea fisheries in the model: offshore longline and offshore driftnet fisheries (driftnet fishing ended in 2008) and coastal trapnet and coastal gillnet fisheries. Thus, combined harvest rate for offshore fisheries is calculated as the complement of the proportion that survives from both driftnet and longline fisheries:

$$HR_{a,y}^{offs} = 1 - \left(\left(1 - HR_{a,y}^{DN}\right) \cdot \left(1 - HR_{a,y}^{LL}\right)\right).$$

Similarly, combined harvest rate for coastal fisheries is the complement of the proportion that survives from both coastal trapnet and gillnet fisheries

$$HR_{a,y}^{coast} = 1 - \left(\left(1 - HR_{a,y}^{TN}\right) \cdot \left(1 - HR_{a,y}^{GN}\right)\right).$$

In combined harvest rate graphs (published in the working group report) MSW refers to sea ages 2 and older, as the catchability in each fishery is considered to be equal for those age groups.

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Recreational trolling. The model framework was originally designed to account only for commercial sea fisheries. However, the significance of recreational sea trolling has increased during the past 10–15 years, its catch corresponding to about 20–30% of total commercial offshore catch during that period. Currently, the trolling fishery is accounted for in the historical model as part of the (commercial) longline fishery according to the following steps:

1) Longline and trolling catches are pooled.

2) Longline effort is increased with the same proportional magnitude as the trolling catch so that the longline CPUE remains unchanged.

Similarly, in future projections, trolling is treated as part of the longline fishery by using expert evaluated trolling catches for future years and increasing the longline effort with a magnitude that covers these catches. Trolling catch is assumed to be constant over the different effort scenarios evaluated by the working group, since the TAC affects only commercial fisheries.

Ongoing work aims at treating trolling as a separate fishery. Data on total trolling effort is not available, however, and the trolling fishery therefore requires a different modeling approach compared to commercial fisheries.

C.1.10 Uncertainties affecting the assessment results

Data deficiencies

The main information on the exploitation of wild salmon in the Baltic comes from mark–recapture data. The problem with these data is that they are geographically biased. All tag recapture data are representing salmon from AU 1–3, and wild salmon have been tagged only in AU1.

The fishing effort of the Swedish coastal fisheries by trapnet and other gears (predominantly gillnet fisheries) for the entire time-series have been based on the CPUE of Finnish coastal fisheries. Also, the proportion salmon which is mauled by seals in the entire trapnet fishing is based on reports of the Finnish fishermen.

Uncertainties expressed by the prior probability distributions of the model parameters

For rivers with a lot of data such as Tornionjoki, the influence of data heavily overrides the expert based priors of the potential smolt production capacity (PSPC), which thus can become updated substantially. Among rivers with less data, such as the river Öreälven, the priors have more influence on the resulting posterior probability distributions of PSPC.

Prior probability distributions for the parameters of the sea mark–recapture model have been provided by twelve experts based on previous studies, on literature, on the experts' experience or were subjective expert estimations in case no other information was available. A table with all prior probability distributions are described in Michielsens *et al*. (2006a). With exception of the prior probability distributions of the catchability coefficients, the prior probability distributions for the model parameters have been given rather informative distributions. Sensitivity analyses have indicated, as could be expected, that results are to a large extent dependent on the prior probability distributions for the reporting rate and biological model parameters and to a very limited extent on the prior probability distributions for exploitation rates (Michielsens *et al*., 2006a).

Uncertainties regarding the model assumptions and model structures of the estimation model

Given the large number of different methodologies used for the assessment of Baltic salmon stock, the model assumptions are described in the sections relating to the different methodologies.

Walters and Korman (2001) have pointed out that for depleted stocks when the spawning stocks increase rapidly after long periods of low abundance, this may result in locally intense competition within those reproduction areas that are still being used. This patchy habitat use may impose local density-dependent effects, which may diminish in the longer run (after several generations) once spawners have dispersed to fully re-establish the natural or most productive structure of habitat use (Walters and Korman, 2001). If this phenomenon is valid for the Baltic salmon populations, our analysis of the recent stock–recruit information underestimates long-term (full) carrying capacity of the Baltic rivers.

Tag shedding and mortality

Possible sources of error in application of results from tagging experiments include the question of differential mortality between tagged and untagged fish and when this (possible) mortality occurs, also tag shedding (loss of tags) and whether this is related to the size of the fish. Possible differences in growth rates of tagged and untagged fish could also be a problem. The reporting rates (proportion) of the tags caught in different fisheries are also important pieces of information to be able to use tagging data.

A considerable mix-up of these different factors is likely and in most cases, it is difficult to keep the different factors apart.

It is vital for the tagging studies to have at least an overall estimate for tag shedding rate. Some information on salmon can be found in the data from Swedish brood-stock fisheries in Gulf of Bothnia based on numbers of fish released in each year in 1987–1998 and the number of fish recovered in year 1990–1999. It is assumed that all tags in these fisheries are reported and therefore they can be used to elucidate the combined effect of tag shedding and difference in mortality between tagged and untagged. If the recovery rate in brood-stock fisheries is compared with tag recoveries in rivers and river mouth areas, data on reporting rates can be calculated.

It is assumed that the best dataset is available from River Dalälven, which has a meticulous control of the number of the fish caught in the brood-stock fishery. There is also a very good organization of the angling in this river and the catch statistics in this river is therefore assumed to be of particularly high class. The data from this river suggests that the tag shedding/mortality remove about 30% of the number of tags.

Misreporting in the Polish longline fishery

Polish salmon catches has been corrected for the fact that a large proportion of the catches is suspected to be misreported as being trout. Polish salmon catches have therefore been calculated based on biological information on species composition in the area (see further explanations in Section B and in the working group report). High-quality inspections or similar information are needed to give a reasonably precise estimate of the salmon catch in the Polish longline fishery, and to evaluate if the deviations from the corrected values are large enough to affect the assessment results.

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Comparison between model predictions and independent empirical information

Independent empirical information is important for the evaluation of model predictions and their key parameters. Over the years, repeated comparisons with different kinds of such independent information have been performed, and in several cases, these comparisons have prompted modifications or extensions to the full life-history model. For example, some years ago sea temperature data were introduced as a covariate of age-specific maturation rates, based on the analyses and development work carried out in the last inter-benchmark protocol (ICES, 2012b) and thereafter. Also, as described below, comparisons between model predictions and empirical results from genetic mixed-stock analyses (MSA) have been used over the years to verify model performance (e.g. ICES, 2014).

Previous comparisons between stock proportion estimates in catches (based on MSA) and model predictions of the stock composition in the Main Basin indicate that there is a good overall agreement between the two methods in the proportion of both wild and reared salmon. Not only the overall proportions of wild and reared salmon are in agreement, but also AU specific and even stock-specific catch proportions are in fair agreement between the model results and the results of genetic analyses of catches. Apparently, previous changes in the model structure and the expanded use of available data (fitting the model to proportion of wild vs. reared salmon in catch samples from offshore fishing, and to spawner counts in Dalälven, Luleälven, Tornionjoki/Torneälven and Simojoki) has greatly improved the performance of the model.

Nevertheless, there is a possibility that the present offshore fishing occur in areas where some stocks may be partly missing. For example, the reared Daugava salmon has been observed in unexpected small proportions in the offshore catch samples which are taken from the Subdivisions 25 and 26 in the southern Main Basin. Neva salmon has been stocked in the Finnish Bothnian Sea; salmon of this strain has been shown to migrate shorter distances at sea than the strains of the Gulf of Bothnia salmon. Moreover, reared large smolts stocked in the Gulf of Bothnia are shown to stay on more northern feeding areas than smaller smolts. This together with the most recent spatial aggregation of offshore fishing to the southwesternmost part of the Baltic Sea may lead to stock/origin/strain specific differences in the offshore harvesting, which is not taken into account in the current model assumptions. Therefore, it would also be important to further explore the distribution pattern of the feeding salmon vs. the distribution of the fishery.

C.2 Salmon in eastern Main Basin (AU 5)

For AU 5 salmon, there is no analytical assessment model developed. The assessment of population status is mostly qualitative and takes into account trends in parr densities and (offshore) exploitation rates. Moreover, current smolt production estimates are compared against the available expert opinions on river-specific potential smolt production capacity (PSPC, see Section E), but no analysis of the stock–recruit dynamics exist at the moment.

An overview of the different types of data available for salmon in AU 5 can be found in Table C.2.1. Expert opinions on PSPC (and brief descriptions how these were obtained) are presented in the working group report (Tables 4.2.3.2 and 4.2.3.3).

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Table C.2.1. Overview of the different types of data available for salmon in AU 5. The table also indicates for which stocks the current assessment methodology is estimating smolt abundance, spawner abundance and associated stock–recruit function. River categories: W=wild, M=mixed, R=reared.

River identification					Data										Estimates		
River	ICES subdiv	Category	Country	Index River	M74 data	Electrofishing survey	Smolt trap data	Tagging data*	Fish ladder/counter data	Broodstock fishery	River catches	Age structure**	Genetic baseline	Smolt estimates	Spawner estimates	S/R parameters
Assessment group 5: Eastern Main Basin																
Pärnu	28	M	EE			x										
Salaca	28	W	LV	x		x	x	x	(x)		x	x	x			
Vitrupe	28	W	LV			x										
Peterupe	28	W	LV			x										
Irbe	28	W	LV			x										
Uzava	28	W	LV			x										
Saka	28	W	LV			x										
Barta	28	W	LV/LT			x										
Gauja	28	M	LV			x		x		x		x	x			
Daugava	28	M	LV			x		x		x	x	x	x			
Venta	28	M	LV			x				x	x	x	x			
Nemunas	26	M	LT			x							x			
Minija	26	R	LT													
Lielupe	28	R	LV					x								

*** Continuous tagging of smolts, predominantly with Carlin-tags or Pittags**

**** Adult age data, from scale reading or length-based separation of grilse and multi sea winter salmon**

C.3 Salmon in Gulf of Finland (AU 6)

Similar to the AU 5 stocks, there is no analytical assessment model in use for the AU 6 salmon. Development of a Bayesian stock-assessment model for the Gulf of Finland salmon populations has taken place in 2017-2018. The work is still in process but the model will most likely be implemented in the near future. Currently, however, the assessment of population status is mostly qualitative and takes into account trends in parr densities and various, mostly qualitative, information about the level of exploitation. Also here, current smolt production estimates are compared against the available expert opinions on river-specific potential smolt production capacity (PSPC, see Section E), but no analysis of the stock–recruit dynamics exist at the moment.

An overview of the different types of data available for salmon in AU 6 can be found in Table C.3.1. Expert opinions on PSPC (and brief descriptions how these were obtained) are presented in the working group report (Tables 4.2.3.2 and 4.2.3.3).

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Table C.3.1. Overview of the different types of data available for salmon in AU 6. As can be seen, there is no analytical assessment model developed which could estimate smolt and spawner abundances, and associated stock–recruit functions. River categories: W=wild, M=mixed, R=reared.

River identification					Data									Estimates		
River	ICES subdiv	Category	Country	Index River	M74 data	Electrofishing survey	Smolt trap data	Tagging data*	Fish ladder/counter data	Broodstock fishery	River catches	Age structure**	Genetic baseline	Smolt estimates	Spawner estimates	S/R parameters
Assessment group 6: Gulf of Finland																
Kunda	32	W	EE			x							x			
Keila	32	W	EE			x							x			
Vasalemma	32	W	EE			x							x			
Purtse	32	M	EE			x					x					
Selja	32	M	EE			x					x					
Loobu	32	M	EE			x										
Valgejõgi	32	M	EE			x					x					
Jägala	32	M	EE			x					x					
Pirita	32	M	EE	x		x	x	x	x		x	x				
Vääna	32	M	EE			x					x					
Luga	32	M	RU				x						x			
Kymijoki	32	M	FI			x	x	x	x				x			
Neva	32	R	RU										x			
Narva	32	R	RU/EE										x			

* Continuous tagging of smolts, predominantly with Carlin-tags or Pittags

** Adult age data, from scale reading or length-based separation of grilse and multi sea winter salmon

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D. Short- and long-term projections

Salmon in AU 1–4

Model used: Simulations based on full life-history model

Software used: R (R Development Core Team, 2009)

Initial stock size: Stock and year specific numbers of smolts. Stock and year-specific numbers of fish by sea age at sea on the first of May. Uncertainty included.

Maturity: Age-specific maturation rates estimated by the full life-history model. Uncertainty included.

F and M: M is divided between post-smolt stage and 'adult' ages. M for post-smolt stage ('Mps') is assumed to hold the autocorrelation structure observed in the past, and the median value of it is assumed to return to a chosen value in the long term. M for 'adult' ages is same as estimated by the full life-history model. M74 mortality is assumed to vary within the limits of the observed range of values, but assuming the same autocorrelation structure as observed in the past. Fishery specific F's are dependent on assumed future effort through catchabilities which are estimated in the full life-history model.

Weight-at-age in the stock: Not used.

Weight-at-age in the catch: Not used.

Exploitation pattern: Same as in the last observed year.

Intermediate year assumptions: Same exploitation pattern as in the last observed year. Offshore fishing effort in the first months of the year are assumed known (no uncertainty) based on observed effort in the last months of the last observed year and by assuming similar division of effort between winter as observed one year before. Coastal fishing effort is assumed to be the same as in the last observed year.

Stock–recruitment model used: Stock-specific Beverton–Holt models estimated by the full life-history model. Uncertainty included.

Procedures used for splitting projected catches: Projections provide predictions of total removals for a given effort level. Splitting catches is based on the last observed year. The relative proportions of reporting, unreporting, misreporting and discarding are assumed to stay the same as in the last year with observations.

Salmon in AU 5–6

No stock projections are made.

D.1. Description of stock projections

Projections are carried out for all rivers in assessment units 1–4. Due to the length of the life cycle of salmon and the chosen reference points projections are extended to at least six years into the future. There are no separate short-, medium- and long-term projections with different approaches.

The effects of various TAC decisions are screened stepwise by decreasing/increasing the last observed effort and by applying these alternative effort levels into the future. The stock projections are also based on scenarios for future post-smolt survival and M74 mortality.

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Methods

In order to make forward projections, the salmon life cycle with the most relevant life-history parameters are copied from the full life-history model into a separate calculation platform. Joint posterior distributions describing the latest knowledge of the number of smolts and population parameters are also derived from the full life-history model (see Section C.1.9) and stored in the form of indexed MCMC chains. The estimates are stored up to the last year with observations about the parameter in concern. Scenarios are run by using R software (R Development Core Team, 2009).

Assumptions regarding biological parameters

The population dynamics for the stock projection analysis is similar to the full life-history model but lacks the process errors in the different survival parameters. In addition, only average annual M74 mortality is included in the stock projections instead of river-specific mortalities. For Ume/Vindelälven, the mean of the last 3 years' values for the proportion of females among multi-sea-winter spawners, and mortality after counting are used in projections.

The two annually varying key parameters determining the natural survival of the salmon, i.e. post-smolt survival (Mps) and survival from M74 mortality are assumed to vary within the limits of the observed range of values, but assuming the same autocorrelation structure as observed in the past. The forward projection for Mps begins already from the assessment year -1 because of the absence of data containing information about the survival in that year. For M74, the projections start from the assessment year. Simulations are typically run for only one scenario about Mps: the average value for years 2014–2017. Alternative scenarios can be executed if e.g. there are reasons to believe that Mps may change in future. Survival from M74 mortality is expected to return to the median survival observed in the historic time-series.

Assumptions regarding development of fisheries

Scenarios for fisheries are implemented by making different scenarios for future development in effort. As an example, the key assumptions underlying the stock projections used by WGBAST in 2019 for fishing year 2020 (ICES, 2019) can be found in Table D.1.1.

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Table D.1.1. Assumptions and removal scenarios for 2020. Figures referred to in the table can be found in ICES (2019).

Scenario	Total commercial removal (dead catch) for year 2020
1	Removal that corresponds to ICES advice for fishing year 2019
2	20% increase to scenario 1
3	20% decrease to scenario 1
4	F0.1 approach (commercial removal)
5	zero fishing
6	recreational fishing only
7	No recreational fishing (no trolling, no river fishing). Commercial removal as in sc 1.
8	100% increase to scenario 1
	In all scenarios we assume that the commercial removal (wanted catch reported) covers 53% of the total commercial sea fishing mortality, whereas 47% of this mortality consists of discards, misreported and unreported. Recreational fisheries in 2020 are assumed to have a catch that corresponds to the average effort in these fisheries in 2016-2018 period, whereas in future years the effort component is the same for these fisheries but the catch varies according to abundance. (See text for
	Post-smolt survival of wild salmon
	Average survival between 2014-2017 (Figure 4.3.2.2)
	Post-smolt survival of reared salmon
	Same relative difference to wild salmon as on average in history
	M74 survival
	Historical median (Figure 4.3.2.2)
	Releases
	Same number of annual releases in the future as in 2018
	Maturation
	Age group specific maturation rates in 2019 are predicted using january-march 2019 SST data. For other years, average maturation rates over the time series are used, separately for wild and reared salmon. (Figure 4.3.2.3)
	Ume/Vindelälven
	Average proportions 2016-2018 (no. spawners passing ladder, MSW sex ratio passing ladder, extra mortality after ladder)

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European Commission has proposed to set TAC based on harvest rule F=0.1 (European Commission, 2011). TAC based on this harvest rule can in principle be calculated directly from the stock abundance estimate. However, guidelines would be required to specifying how uncertainties in estimates should be taken into account and what would need to be assumed about the development of fisheries which is not controlled by TAC.

Evaluation of management alternatives

The future development of smolt production under different scenarios is evaluated in two ways:

1) River-specific probabilities to meet the 75% final year R_0 target is calculated for each future year, with a special emphasis on the smolt production of the years mostly affected by management measures in the year the advice is given for.

2) Changes in the river-specific probabilities to meet the 75% target from the current situation compared to one full generation into the future. The length of a salmon generation is on average seven years for AU 1–3 and six years for AU 4 river stocks. By comparing the current status with the status one generation ahead, the effect of a cyclic fluctuation in population abundance can be removed and the effects of different effort scenarios on the future development of stocks can be better evaluated.

Uncertainties regarding the stock projections

There are two differences between assumptions of the full life-history model and the population dynamics model which is used in projections.

1) Process error is lacking in all other survival processes except in recruitment (S/R dynamics). Excluding process error from the predictive model leads to results that are less variable than they would be if process errors in survival were included. Deterministic survival process in forward projections may underestimate the variation in probabilities to reach management targets in predictions.

2) Average values for M74 are used in the projection model instead of river-specific values used in the estimation model. River-specific differences in M74 mortality are therefore lost, which may lead to generally more uncertain river-specific projections.

Assuming a known offshore fishing effort in the interim year underestimates the uncertainties in stock size at the beginning of the year for which advice is given.

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E. Biological reference points

There are no objectives with corresponding reference points agreed for the current management of Baltic salmon. In addition, there are no 'rules' or guidelines for how fast (within which time frames) weak salmon stocks should recover, or when a certain proportion of all stocks should have obtained their management goal. Therefore, under current conditions with two separate TAC regulating sea fisheries in SD 22–31 and 32, respectively, and many stocks with varying status, any catch advice for the mixed-stock fishery on Baltic salmon will be somewhat subjective and associated with trade-offs between exploitation levels and time to fulfill management objectives.

In the absence of agreed management objectives, the working group evaluate the probability to reach 50% and 75% of the **Potential Smolt Production Capacity** (PSPC) in each river. Reaching at least 50% of the PSPC by 2010 in each river was the objective of the Salmon Action Plan (SAP), defined by the former IBSFC. Reaching at least 75% of the PSPC has been suggested by ICES if the plan is to recover salmon river stocks to the MSY level (ICES, 2008b; ICES, 2008c). The objective of reaching at least 75% of the PSPC is also adopted in the Commission's proposal for establishing a multiannual plan for the Baltic salmon stock (European Commission, 2011), and is also used as a basis for ICES advice on fishing possibilities. The PSPC estimates therefore form the basis of the current reference points for the assessment of the Baltic salmon stocks.

There is a considerable amount of uncertainty associated to these reference points. For salmon stocks in AU 1–4, all model parameters, including PSPC, are updated every year when new data become available, and comparisons of the assessment year's and the previous year's PSPC estimates are provided in the annual WGBAST report.

For salmon in AU 5 (eastern Main Basin) and AU 6 (Gulf of Finland), no analytical assessment model has been developed (see Sections C.2 and C.3 above). Preliminary Potential Smolt Production Capacity (PSPC) values have been proposed based on expert opinions but no stock–recruit data exist at the moment, precluding analytical updating of these estimates with existing assessment data. Determination of status of rivers in these units is based on a qualitative consideration of trends in parr densities and exploitation rates, as well as on comparison of current smolt production with the expert opinions about PSPC.

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