Tana/Teno Monitoring and Research Group

Tana/Teno salmon stock recovery and sustainable fisheries

Report from the Tana/Teno Monitoring and Research Group 1/2022

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Summary

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Since the early 2000s, the entire Tana/Teno salmon stock complex has had a negative development, recently culminating in a situation with no exploitable surplus left and a complete closure of the salmon fishery in 2021 and 2022. Concurrently, neighboring rivers have had the opposite trend, recovering from a precarious stock situation in the 1990s to reaching their respective management targets in combination with high catches.

An attempt was made to rebuild the Tana/Teno salmon stocks with the new agreement in 2017. But while this agreement successfully reduced the overall exploitation rate of Tana/Teno salmon, it also coincided with a prolonged period of poor sea survival from 2019 and onwards. Results from the Utsjoki video monitoring indicates that the return rate of grilse (1SW salmon) 2019-2021 was 18-40 % of the previous average. Consequently, the reduction in exploitation rate from the 2017 agreement was not large enough to result in any increased spawning stocks. With the 2021 fishing closure, a clear effect was found in spawning stock sizes across the Tana/Teno river system, an increase that is also expected to be found in 2022.

All evaluated stocks in Tana/Teno are currently found to be at a level that indicates the need for a stock recovery plan. In order to have a successful recovery, several key elements have to be in place. Firstly, an unambiguous set of criteria needs to be established concerning the relation between exploitation and the status assessment. A threshold for formal stock recovery should be established (corresponding to going from the yellow to the orange status category) and associated with lowered exploitation to counter what is a seriously depleted salmon status. The four largest salmon stocks of the Tana/Teno system (the main stem, Anárjohka, Kárášjohka, Iešjohka) are however in an even more precarious situation, having fallen from orange to the red status category. This latter category is reserved for a situation with no exploitable surplus over at least two of the last four years. This is a critical situation and no fishing should be permitted.

The negative stock development in Tana/Teno is the result of having removed too many spawners over a too long period. The pressure of a chronic high accumulated exploitation rate has consistently pushed the salmon stocks towards a situation with low fish density. In recent years, fisheries biologists have become increasingly aware of the dangers of pushing fish stocks towards very low densities as the stocks then become increasingly vulnerable to natural mortality factors. This phenomenon is called Allee effects or depensation. With Allee effects, the stock growth rate will decline at low stock densities, even to the point of becoming negative (meaning that more individuals die than is replaced by recruitment, effectively leading to a collapse). Because of Allee effects, getting a recovery process to effectively start might be problematic and to counter the existence of Allee effects, care should be taken to reduce exploitation as much as possible during the first generation of a recovery process.

In order to help finding a robust recovery process and establish criteria for a reopening of the salmon fisheries following two years of no fishing, the Tana/Teno Monitoring and Research Group (MRG) was tasked with answering a number of questions summarized below.

The first question concerned criteria for safely reopening the salmon fisheries, including how large the exploitable surplus should be. Most importantly, stocks placed in the red status category are in a critical situation and should not be exposed to any exploitation for any reason. This is particularly true for exploitation from a mixed-stock fishery. A sea survival returning to more normal levels would be followed by increased return rates of adult salmon and would enable the most critical stocks to return to a situation with at least some exploitable surplus. This might allow for a limited fishery, but care

should be taken to 1) use forecasting to establish a quota that can be safely exploited within the terms of the recovery process, and 2) establish a regulation that allows for strict enforcement in order to avoid overexploiting the quota. We outline a concrete system for achieving this in the report.

The second question concerned the precision of monitoring used to establish estimates of exploitable surplus, and what safety margins would be needed to counter uncertainty in the estimates. The existing monitoring is likely to continue to be an effective tool at tracking stock status and developments in pre-fishery abundance. However, we need a probability framework to enhance our assessment of the recovery process with probability projections towards a successful recovery. These needs can be met with a Bayesian population model based on the Baltic salmon population model tailored to the needs of the Tana/Teno river system.

The third question concerned recovery time span. Here it is important to realize that a salmon stock recovery will have a stair-shaped form, increasing in steps towards the overall recovery goal. The lengths of these steps follow the salmon generation length, meaning that an effect of a decrease in exploitation in year 1 will not be observed in the number of returning adults until 7-8 years later (7-8 years being the time the salmon needs in order to hatch from eggs, live as juveniles, smoltify and then grow at sea before returning). The shortest possible recovery time would then be one generation, followed by two generations at approximately 15 years.

The fourth question concerned different strategies for combining recovery and a sustainable fishery and we provide a detailed discussion of three different approaches. The first strategy involves using the main stem sonar counts to dynamically adjust the fishery during the fishing season. The counting could either be used to provide a reopening criteria (closed fishing at the start, then a limited reopening later in the summer if the count exceed a preagreed criteria) or a criteria for closing (if the counting show a weaker than expected run of salmon). There are difficulties to these approaches. The second option is likely not a viable tool during recovery, but could possibly be used as a tool to increase the likelihood of keeping a stock at or around its spawning target. The first option might work during a recovery, but with the caveat that it might fail to protect late-run stocks such as the main stem and Anárjohka/Inarijoki salmon. For this reason, using the main stem sonar might work best as an additional criteria for the quota/forecasting-based approaches.

The second strategy concerned using forecasting to establish a total quota for a fishing season. There is a strong correlation between the number of 1SW one year, the number of 2SW the following year and the number of 3SW two years after. We demonstrate that this correlation were able to provide a fairly accurate forecast of the pre-fishery abundance in years with a normal sea survival. The forecasting underestimated the pre-fishery abundance in years with higher than normal sea survival, which is a consequence that have no adverse effects on the recovery. However, the forecasting severely overestimated the pre-fishery abundance in years with low sea survival, and additional criteria should therefore be used to avoid this. One mitigating option could be the use of the main stem sonar count.

The third strategy concerned the use of quotas in different forms. Our evaluation here finds that general and non-dynamic daily and seasonal quotas are unlikely to protect against overexploiting during the recovery process. These measures are expected to perform a bit better for keeping the stocks at or around their spawning target.

The last question concerned the potential effects of sea survival, predation, climate change and pink salmon on the recovery. Overall, sea survival emerges as a key factor. With the current low survival, fewer than expected salmon return and the scope for exploitation in combination with recovery is exceedingly restricted. An improved sea survival will increase the potential for reopening the fishery. Predation is significantly affecting salmon stock recovery when stocks are depleted down to the most serious status categories. Attempting predator control in this situation is likely difficult with uncertain effects, some of which might even be negative for salmon. Predator control is therefore not advisable, and restricting mortality through exploitation is likely to be a significantly more efficient approach. Climate change will affect the Tana/Teno salmon, both negative and positive. Very little is still known about the possible effects of pink salmon. What is certain, however, is that significant attempts to eliminate the pink salmon will have adverse effects on salmon and the prospect of successfully recovering the salmon stocks, further limiting the scope for fishing in odd years during the stock recovery process.

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The Tana/Teno Monitoring and Research Group

The new Tana/Teno Monitoring and Research Group (hereafter MRG) was formally appointed in 2017 based on a Memorandum of Understanding (MoU) signed by Norway and Finland in December 2017. The mandate of the MRG is:

1) Deliver annual reports within given deadlines on the status of the salmon stocks, including trends in stock development.
2) Evaluate the management of stocks considering relevant NASCO guidelines.
3) Integrate local and traditional knowledge of the stocks in their evaluations.
4) Identify gaps in knowledge and give advice on relevant monitoring and research.
5) Give scientific advice on specific questions from management authorities.

The MoU is based on the Agreement between Norway and Finland on the Fisheries in the Tana/Teno Watercourse of 30 September 2016. This agreement outlines a target- and knowledge-based flexible management regime for salmon fisheries in the Tana.

According to the MoU, the MRG shall consist of four scientists, two appointed by the Ministry of Agriculture and Forestry in Finland and two by the Ministry of Climate and Environment in Norway. The currently appointed members are:

- Jaakko Erkinaro (Finland, scientist working at Natural Resources Institute Finland (Luke) in Oulu)
- Panu Orell (Finland, scientist working at Luke in Oulu)
- Morten Falkegård (Norway, scientist working at Norwegian Institute for Nature Research (NINA) in Tromsø)
- Anders Foldvik (Norway, scientist working at NINA in Trondheim)

1 Introduction

Fish stocks are an important part of the world food system. During the 1970s and 1980s, most fish stocks all over the world seemed to be decreasing, mostly as a result of continued overfishing (e.g. Ludwig *et al*. 1993). Humans have a long history of unsustainable fisheries. At archaeological sites in Congo, 90000-year-old bone harpoons used for fishing have been found along with abundant remains of their main fishing target, a 2 m long freshwater catfish that went extinct, forcing the fishermen to move on to other fish species (Yellen *et al.* 1995). This pattern of fisheries exterminating the fish stock they originally relied on, and then moving on to other species, has continued ever since (Cushing 1988).

The patterns of collapsing stocks of the 1980s led to a variety of actions aimed at reversing the declines and recovering stocks (Sissenwine *et al*. 2014). A recent analysis (Hilborn *et al.* 2020) demonstrate that stocks that are scientifically assessed and managed in an adaptive target-based regime are doing on average twice as good (in terms of reference point attainment and avoiding overexploitation) as stocks that are less well assessed and managed. A particularly close example is stocks of the north-east Atlantic that have a general pattern of increasing biomass following the implementation of a science-based management and adequate policies that have significantly reduced fishing mortality (Zimmermann & Werner 2019).

The experiences of successfully managing and recovering marine stocks are directly relevant for the current management directions seen for salmon stocks, as recommended by NASCO. With declining salmon stocks on both sides of the Atlantic, NASCO parties agreed to adopt and apply a Precautionary Approach to the management of salmon. In the Precautionary Approach, stocks should be maintained above stock-specific conservation limits using management targets, threat factors should be identified, risk assessments should be incorporated at all levels, pre-agreed management actions should be formulated in the form of procedures to be applied over a range of stock conditions, the efficiency of management actions should be assessed and stock recovery programs should be implemented for stocks that are below their conservation limits.

The basic principles of the NASCO Precautionary Approach were to a certain extent implemented in Tana in 2017 with a new agreement between Norway and Finland. This agreement emphasises the use of management targets as a primary tool when assessing stock status, and the establishment of pre-agreed management actions that can be triggered when stock status fall beneath a designated threshold level. With this management procedure, Tana/Teno salmon management is turned into a transparent and predictable adaptive knowledge-based regime, in line with the management systems that have proved most efficient for marine fish.

A basic premise of the Precautionary Approach is a reversal of the burden of proof. Traditionally, restrictions in fisheries have been established on the basis of needs identified from research and monitoring information. With the Precautionary Approach, this procedure is turned upside-down and a fishery should open only when research and monitoring information demonstrates that the fishery will not have unacceptable effects on the resource. This can be achieved by monitoring fish abundance, for instance establish biological reference points (spawning targets) that are the number of salmon that should survive the fishing season each year to ensure a sustainable level of recruitment. Salmon management should then balance exploitation levels to ensure stocks are kept above the reference points while also meeting the local socioeconomic needs.

The overall salmon stock situation in Tana/Teno has become increasingly precarious over the last two decades. The estimated total pre-fishery abundance levels have been decreasing, and the latest Tana/Teno Monitoring and Research Group (MRG) status report (Anon. 2021) estimated that the Tana/Teno overall had no exploitable surplus in 2020 and 2021. The headwater areas were most negatively affected (Figure 1). As a result of the lack of an exploitable surplus, all within-river salmon fisheries were closed in 2021 and coastal mixed-stock fisheries exploiting Tana/Teno salmon were also severely restricted. The precarious situation is expected to continue and the Tana/Teno river system was therefore recently closed for salmon fisheries also in 2022.

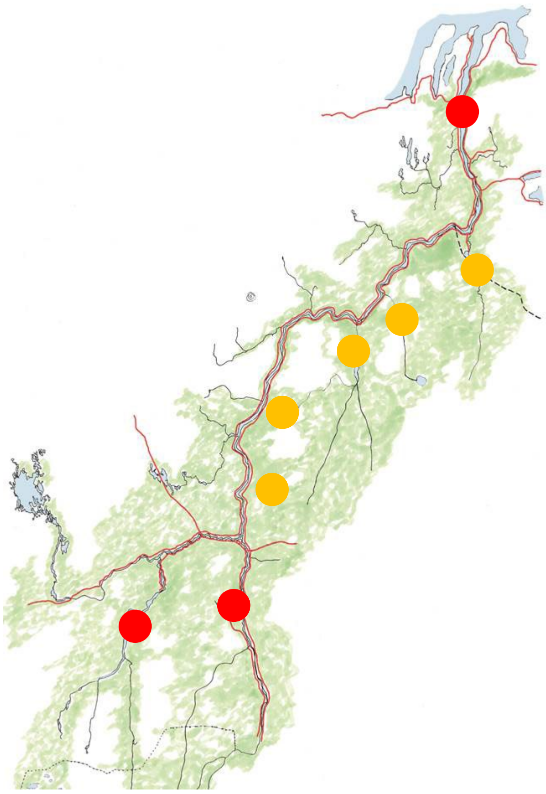

Figure 1. Map summary of the 2018-2021 stock status of the evaluated parts of the Tana/Teno river system. Symbol colour designates stock status over the last four years. Possible colours are: Dark green = overall probability of attaining spawning target higher than 75 %, overall target attainment over 140 %. Light green = overall probability of attaining spawning target higher than 75 %. Yellow = overall probability of attaining spawning target between 40 and 74 %, overall target attainment above 75 %. Orange = overall probability of attaining spawning target below 40 %, stock has had an exploitable surplus in at least 3 of the last 4 years. Red = stock had an exploitable surplus in less than 3 of the last 4 years. Figure from the latest MRG status report (Anon. 2021).

The overall drops in pre-fishery abundances seen in 2020 and 2021 were also observed in other Finnmark rivers, indicating that northern salmon stocks are affected by large-scale unfavourable conditions that have affected sea survival negatively. The low sea survival means that fewer salmon return from sea, decreasing the potential for additional recruitment through stock recovery measures and limiting the exploitation possibilities.

The seriously depleted stock situation in Tana/Teno in combination with unfavourable environmental conditions mean that it is important to establish a robust stock recovery process where any fisheries mortality levels are carefully regulated in order to comply with the recovery. To help in the decision-making on how to combine recovery and fisheries, the MRG was asked to answer a number of questions and chapters 2-6 of this report are structured around these. In addition, we outline a concrete recovery strategy based on pre-season forecasting as a tool to establish a possible scope for salmon fisheries in chapter 7 and outline a recommended monitoring strategy to keep track of the recovery progress in chapter 8.

2 Exploitation and the stock recovery process

Question 1: How large should the exploitable surplus be before it is safe to open the fishery? What criteria should be met before re-opening the salmon fishery?

The questions that were raised mostly pertain to options for exploitation during a recovery process, which is particularly relevant in the present situation with overall poor spawning target attainment in combination with poor sea survival which results in close to no sustainable surplus available for fisheries.

At its core, salmon stock recovery is all about increasing the number of salmon. To achieve this, recruitment has to increase and mortality has to decrease. A stock recovery strategy thus has to be devised, the details of which depend on what goals are set for the recovery process. If the goal is solely to improve stock status, removing all mortality from fishing until the goal for stock status is met will be the obvious strategy. In river systems with habitat degradation, or other anthropogenic disturbances (hydropower, water quality) management options could include habitat adjustments to increase egg to smolt survival. This is not an option in the Tana/Teno as the anthropogenic impacts on the instream habitat are marginal. Removing all mortality from fishing until the spawning target is reached will also be the strategy that has the highest chance of stock recovery and least chance of populations going extinct (Lande *et al*. 2003).

Salmon populations fluctuate stochastically with both environmental and demographic components. High environmental variance and variability in individual survival and reproduction can lead small populations (relative to carrying capacity/spawning target) into extinction trajectories (Lande *et al*. 2003). Given the changes in sea survival observed during the recent years, managers should consider the real possibility that even a complete fish moratorium over a number of years might not be enough to ensure rapid recovery.

Choice of harvesting strategy will have a large effect on the likely outcome of the recovery and long-term status of the stocks. The different harvesting strategies shown in Figure 2 will have different effects on both the expected mean population size and yield, but also have differences in yearly variations in catch. It has been shown that threshold strategies will give the highest yield over time and result in the highest average population size given that the threshold is set equal to the carrying capacity. This strategy also gives the lowest risk of population collapse and extinction. However, threshold strategies can give high variance in annual yield, with many years with no catch. This variability and number of years without harvest, can be reduced by limiting the capacity to exploit the surplus or by using proportional threshold harvesting (Lande *et al*. 2003)

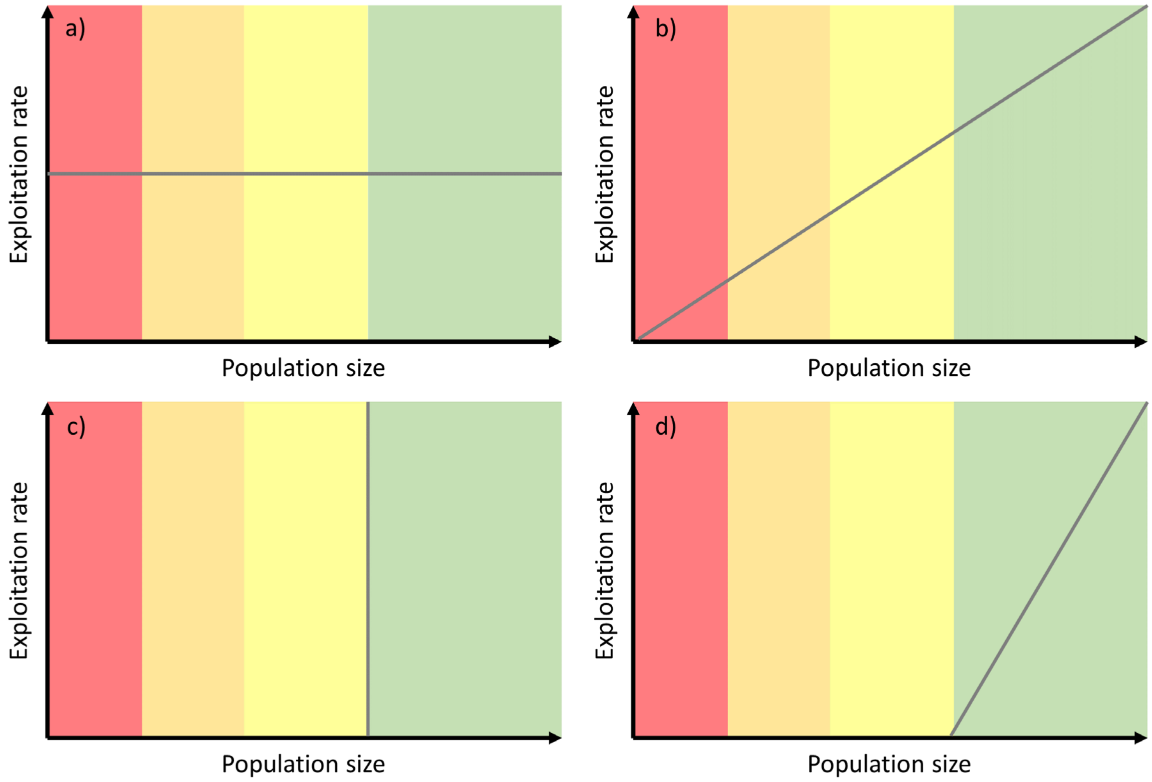

Figure 2. Four basic harvesting strategies with different relationships between exploitation rates and population size (modified from Lande et al. *2003). With a constant exploitation rate (a) the same percentage of the population is harvested regardless of population size. With proportional exploitation (b) the percentage of the populations that is harvested increases with population size. With threshold exploitation (c) no exploitation occurs below the threshold, while all excess can be harvested above the threshold. With proportional threshold exploitation (d) no exploitations occurs below the threshold and proportional exploitation above.*

Successful implementation of all the harvesting strategies will depend on several factors addressed below, including the precision of estimated pre-fishery abundance, the ability of managers to precisely set fishing regulations to achieve the desired exploitation rates and/or have control systems that monitor catches during the fishing season.

The adaptive target-based management procedure commonly adopted in fisheries management, is conceptually shown in Figure 3 and represents a combination of strategies from Figure 2. The colour coding of the figure corresponds to the coding of the summary status maps of the MRG annual status reports (Figure 1). A stock with management target attainment within the green zone to the right in Figure 3 is fully recruited and therefore able to sustain the highest exploitation. When the stock falls below its management target (the yellow zone area of Figure 3), the exploitation ideally should be adjusted to account for the stock not reaching its production potential. With further declines into the orange area, the stock situation has become more urgent, the exploitable surplus has become further reduced and a formal stock recovery plan should be implemented to increase the probability of a successful recovery. Even further to the left, in the red zone, the stock has entered a critical area with no exploitable surplus. Depletion to this level is critical and should really be avoided at all costs. In this situation, all fisheries mortality should be eliminated, especially from mixed-stock fisheries.

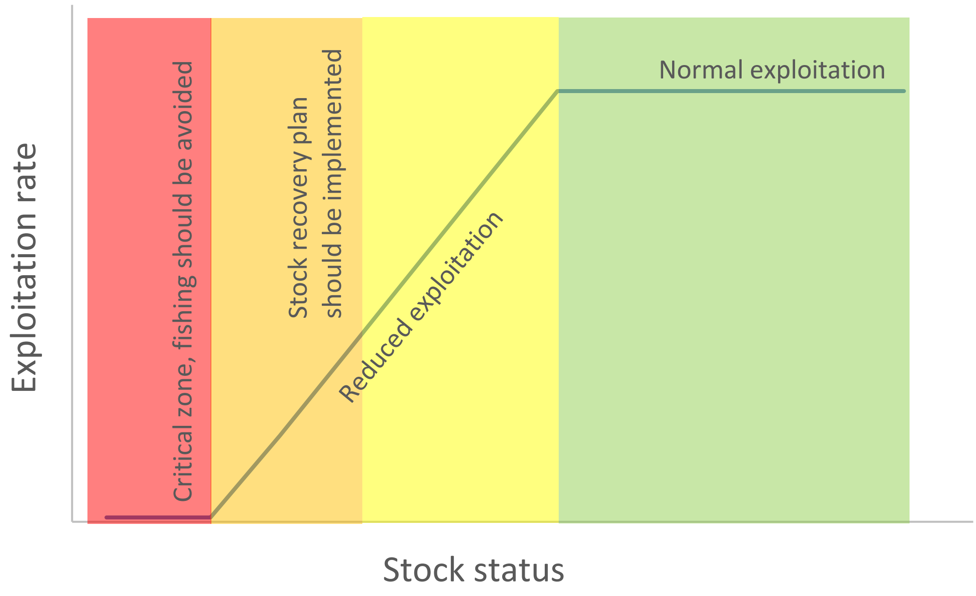

Figure 3. Conceptual relationship between exploitation rate and salmon stock status with differing levels of stock management target attainment in the Tana/Teno river system. The colour coding is equivalent to the colours used in the annual status reports of the MRG.

The question related to how large the exploitable surplus should be before it is safe to open the fishery depends on:

i) What goals the management of the Tana/Teno salmon stocks want to prioritize?

ii) What risks management is willing to take?

iii) What regulations the management are willing to implement?

If the strategy chosen includes a goal of fishing also in years without surplus, recovery will either occur over a longer time period or not at all. It is important here to realise that the cost of and risk associated with incurring adult mortality through fishing is not linear but will increase rapidly as stock status falls down towards the critical red zone of Figure 3. When deciding on a regulatory strategy, it is also important to understand how different regulations might influence the overall exploitation rate. For instance, the overall level of participation and individual effort might differ significantly between a restricted situation with limited fishing options available and a more open situation with a larger number of options available.

The way fishing is currently regulated in the Tana/Teno system is a combination of regulating season length, the number of days fishing can take place using different fishing gear, and a maximum number of sport fishing licences for tourists. Given the exploitation rates after the new agreement in the range of 40-70 % for different salmon populations of the Tana system, the pre-fishery abundance needs to be c. 1.8-3.0 times the spawning target to open fishing at the level of the 2017 agreement if the spawning target is to be met. During the recovery process, additional considerations have to be made, depending on the need for safety margins, the desired recovery time span and the development of other factors that cause salmon mortality. A practical example of how this can be approached is provided in chapter 7.

Many salmon rivers have regulations in the form of either personal or total catch quotas. The effect of setting fishing regulations in terms of quotas, will depend strongly on how they are implemented and what information is used in deciding the quota levels. Setting a total river quota or personal quotas without adjusting these for yearly population size will result in an exploitation rate that is highest for the lowest population sizes (Figure 4). Adjustment of quotas in relation to yearly variations in stock size requires either forecasting and/or in-season stock assessment. Effectiveness of personal quotas will depend on the level of compliance by fishermen, and effectiveness of total river quotas will depend on having a functioning catch reporting system that allows managers to assess when the quota has been reached.

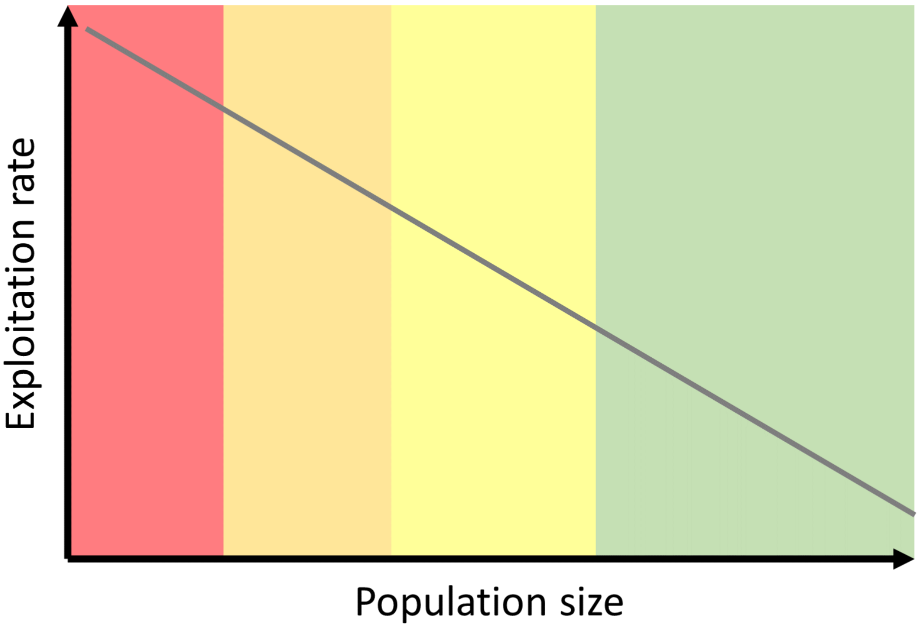

Figure 4. Example of relationship between exploitation rate and population size given a fixed quota.

Finally, it must be clearly emphasized that **before** any exploitation can take place during a recovery process, a proper stock-specific recovery plan has to be developed for all stocks under recovery. This is a basic condition clearly given in the NASCO guidelines, and is a condition that is especially stringent during the first generation of a recovery process. Spawning stock levels are at their lowest during the first generation, resulting in marginal exploitable surplus and the highest natural mortality levels. Any exploitation during this phase, however limited in scope, represents a disproportionate risk of introducing a too high mortality and derailing the recovery. The recovery plan needs to account for possible negative outcomes and provide contingencies that can be implemented to negate a further negative stock development. We further highlight that this crucial prerequisite is still missing in the ongoing negotiations about a limited reopening between Norway and Finland.

3 Monitoring precision and safety margins

Question 2: How precisely can/should we estimate a sustainable surplus in the 15 stocks which are mentioned in the status reports? What safety margins should be integrated in the stock estimates?

Salmon stock monitoring in the Tana system is carried out using multiple methods, depending on the population (tributary/part of the system), and the quality of monitoring data varies accordingly. The most precise information about spawning population comes from snorkelling counts where – in one case – the entire spawning population of salmon in a tributary is counted. The lowest quality information for some tributaries is missing tributary-specific counts and catch data and the estimate is strongly depending on genetic stock identification (GSI) estimating the populations of origin in mixed stock catches in the Tana main stem. Most population assessments fall in between these two extremes and result in combinations of multiple sources of information like counts of salmon entering a tributary (sonar, video), tributary-specific catch data, GSI from catches in the main stem, main stem catch data etc. Overall, the monitoring programme in the Tana is one of the most comprehensive used in Atlantic salmon rivers.

The maximum sustainable exploitation, defined as the number of salmon that can be taken in each year while ensuring that the spawning target is met, equals the production surplus in a year. The sustainable surplus for each monitored population is thus assessed by estimating the number of salmon that exceed the spawning target, in the pre-fishery abundance (PFA) estimate at sea before any salmon fishing, or afterwards, after the fishing season at spawning time. Both estimates at a population-specific resolution can be completed only after each fishing/spawning season, and the implications of the result can only be used for future fishing season. Earlier, the focus in stock status assessment and scientific advice has been on the spawning stock size and attaining the spawning target, while in few recent years with record-low salmon abundance, the emphasis has increasingly included also the PFA, and whether the population contained any surplus even at sea before any salmon fishing.

The question about monitoring precision at different stages and whether there is room for improvement is a complicated one. An easy answer and action would include adding more intensive monitoring sites for populations that currently have lower-quality data for stock status assessment. This would naturally require new resources for monitoring. Another possibility could be the improvement the quality of current estimates. Tributary counts of ascending or spawning salmon likely include limited possibilities for improvement, while the question about quality of the sonar counts in the main stem has been raised in recent years. The main concern is in years when pink salmon enter the Tana, and – as it seems – in rapidly increasing numbers in odd years. Estimating the species-specific numbers of pink salmon and one-sea-winter Atlantic salmon, which are of same size, is challenging in sonar data. Additional information from catches in the lower parts of Tana and from adjacent video recording has been used for distinguishing the species. In 2021, a year with record-breaking pink salmon abundance, salmon fishing was closed in the Tana which added to the difficulty in estimating the abundance of the two species. A research project has been started by Luke with an aim at developing Bayesian modelling for analysing the sonar data and improving the species determination. The modelling learns from various data sources, e.g. the video-backed sonar data from upper tributaries, information on run timing, catch information from earlier years etc. and combines these with the actual sonar data in a probabilistic framework.

Bayesian population modelling could also be used for improving the precision of population estimates in those tributaries that are missing fish count and catch data. This approach would allow using data from data-rich, well-monitored rivers and use this information in producing better estimates for the data-poor tributaries. This strategy should have good possibilities in the future as stock fluctuations and development in salmon populations in different parts of the Tana system appear to follow fairly constant patterns in time.

When it comes to the role of safety margins as a part of the assessments, the answer very much depends on where we are in the recovery process and what the assessments are to be used for. If the main use is a retrospective assessment purely to assess spawning stock sizes in a situation where no fishing will take place until the target attainment over four years is sufficiently good, then the current estimates are ok without any new safety margins. But if the assessment is to be used with new types of regulations using pre-season forecasts and/or in-season estimates to allow for a certain extent of exploitation during the recovery period, then safety margins become much more relevant and important. The main role of the margins would be to minimise the risk of overexploiting a limited quota. The safety margin would have to account for different problems, for instance if the forecast overestimates the pre-fishery abundance or if a quota is not sufficiently enforced. An example of a calculation that can be used to estimate a safety margin is given in the forecast model of chapter 6.

4 Recovery time span

Question 3: Time span for recovery. The original plan according to the 2017 agreement was a full recovery of the stocks within two salmon generations/15 years. Are there arguments to choose alternative options for recovery time? Which arguments and how long time?

The basic goal of a stock recovery is to increase the spawning stock size from a depleted state to a size that equals a pre-defined reference point. This must be accomplished through recovery measures that either decrease mortality or increase production. Due to the nature of the salmon life cycle, there will be a delay from when measures are implemented until effects can be observed in the annual salmon run size. The length of this delay varies between stocks depending on two stock parameters: predominant smolt age and female sea age. The smolt age tells us how many years the juveniles spend in freshwater before undertaking their smolt migration, whilst the female sea age tells us how long the females spend at sea before undertaking their spawning migration. Taken together, the smolt age plus the sea age becomes the generation length.

If the smolt age is 3 years and female sea age 1 year, the generation length would be 5 years. A smolt age of 5 years and sea age of 3 years would translate to a generation length of 9 years. In practice, both the smolt run and the spawning run is a mixture of different ages. Most commonly, smolt in Tana/Teno are 3-5 years while most females stay 2-3 years at sea. Effects of a regulatory measure aimed at decreasing mortality would be spread over a number of years, mostly from 6-9 years, with the majority observed 7-8 years after spawning. For simplicity, a generation length of 7-8 years can therefore be used as a rule of thumb when establishing a stock recovery plan and a recovery trajectory.

Given the above, a recovery trajectory will be ladder-shaped with step length defined by the generation length (illustrated by the horizontal length of the steps in Figure 5) and ladder steepness (the increase from step to step) defined by the extent of decreased mortality that can be achieved. Firstly, the overall recovery period, illustrated by the time the recovery ladder in Figure 5 spends on its trajectory from its present depleted state up to a full-recruited spawning target, will depend on the level of fisheries reductions that are achieved. And secondly, the time needed for recovery must be counted in generations. The choice of recovery time span then basically becomes a choice between one, two or perhaps three salmon generations, with the shortest time span needing the highest fisheries reductions while the longest time span requires less strict reductions (Figure 6).

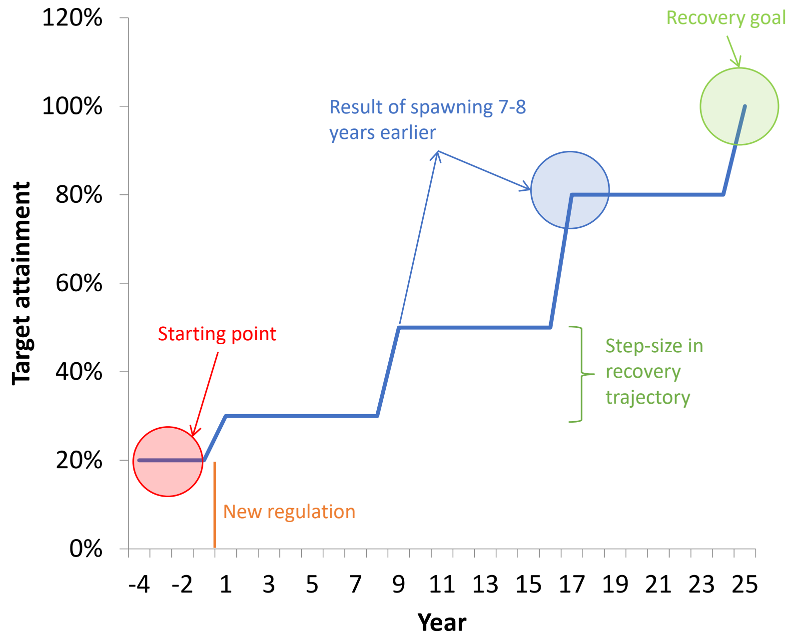

Figure 5. Conceptualized stock recovery trajectory, illustrating a depleted present stock state (starting point), start of recovery (new regulation), generation length, recovery steepness (step size) and recovery end point (recovery goal, which is a fully recruited stock).

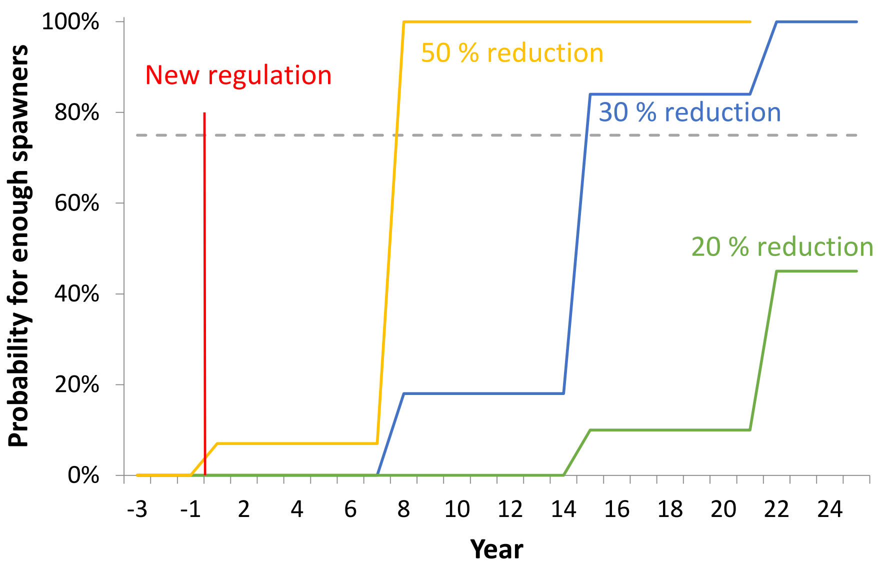

Figure 6. Generalized illustration of alternative stock recovery trajectories based on different mortality level reductions.

The three alternative stock recovery trajectories in Figure 6 are all based on a relatively simple assumption about stock-recruitment, namely that individuals do better as fish density decreases. Fewer fish means less competition, which for instance might mean more food available and better territories with good hiding spots available for each fish. Consequently, a higher proportion of the recruits of each spawner are expected to survive as fish density becomes lower. A higher proportion surviving means that the growth rate of the stock increases, illustrated as an increasing growth rate line towards low densities in Figure 7. This phenomenon is labelled negative density dependence and is a core assumption in classic fisheries biology.

The horizontal line in Figure 7 represent zero stock growth. So with any points below, we have negative growth meaning that more salmon dies than what are produced through recruitment, leading to a declining stock. Points above the line means positive stock growth with more individuals surviving than dying, leading to an increasing stock.

With classic negative density dependence, the stock would have a stable equilibrium point at a relatively high stock size, labelled the carrying capacity to the right in Figure 7. Due to how the current spawning targets are defined, this equilibrium point incidentally equals the stock spawning target. At the equilibrium, recruitment and mortality is balanced. If the fish density were to increase, competition would become harsher and fewer recruits would survive with stock size declining towards the equilibrium point. If the fish density were to decrease a bit, competition would become less harsh and more recruits would survive, with stock size increasing towards the equilibrium. This is a relatively stable natural situation that unfortunately often becomes destabilized through the effect of anthropogenic disturbances, for instance fishing.

In recent years, plenty of evidence has been amassed demonstrating that decreasing fish densities incur a penalty.

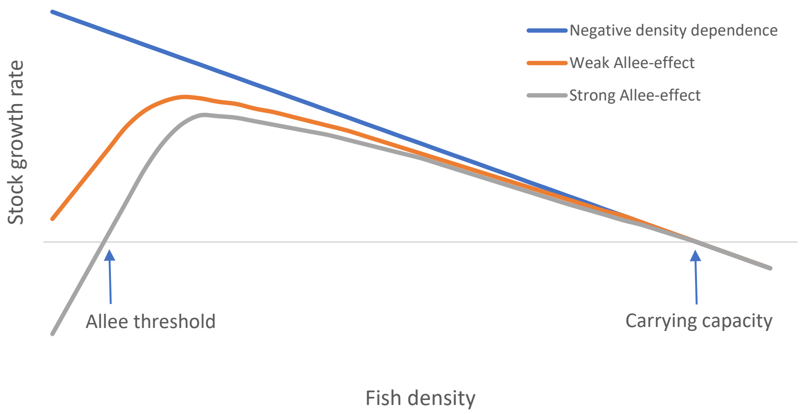

Figure 7. Stock status (with increasing number of spawners towards the right) plotted against the stock growth rate. Growth rate above zero means the number of spawners resulted in an increase in stock size, while growth rate below zero means high mortality and a reduction in stock size. The carrying capacity to the right is a stable equilibrium point at which the stock is fully recruited (spawning target fully attained).

We discussed above the existence of a carrying capacity, an upper stable equilibrium point that an unaffected salmon stock would converge towards. An unfortunate consequence of Allee effects is the possible existence of an additional stable equilibrium point at a very low stock status. If this low equilibrium point is at the lower point of a stock size range with negative stock growth rate (the crossing point to the left in Figure 8), we have what is often termed a predation pit. This is important because the existence of a predation pit (the stock status range in Figure 8 with negative stock growth rate) pose an obstacle to stock recovery. Failing to reduce the mortality sufficiently will result in the situation described with the red arrow in Figure 8, with decreased mortality resulting in an increased number of spawners, but the stock would still be in the predation pit and would still decrease towards the low equilibrium point. The only way to escape the predation pit would be to initiate your recovery with a sufficiently high mortality reduction, ensuring that the number of spawners increase to the right of the predation pit. In that case, stock growth rate becomes positive and the stock recovery will be boosted towards the upper equilibrium point.

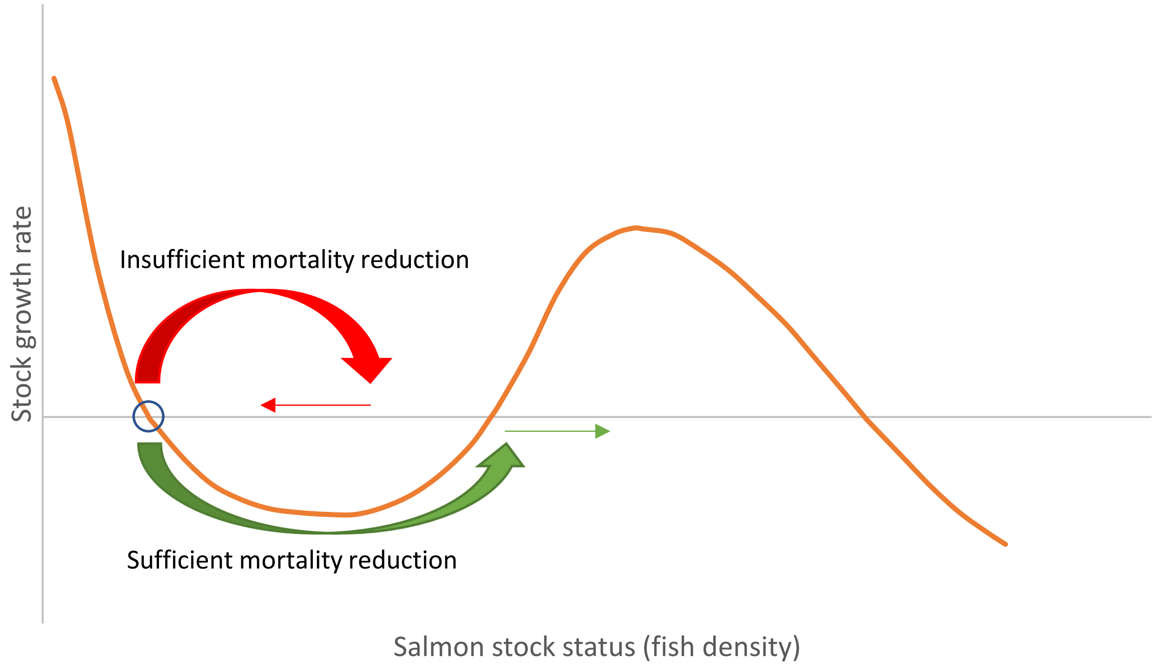

Figure 8. Stock recovery in the presence of a predation pit and a low equilibrium point (crossing point at low stock status marked with a circle). Insufficient mortality reduction (red arrow) lead to spawning stock sizes that are still within the area of negative growth and will cause the stock to decrease towards the low equilibrium point. Sufficient mortality reduction leads to a stock escaping the pit of negative growth, leading to a boost in recovery towards the upper equilibrium point (the crossing point at high stock status).

There is no blatantly right or wrong answer to the decision about recovery time span. However, there are a couple of issues that need to be considered. Firstly, a longer recovery time (2-3 generations) would allow for the most expansive fishery during the recovery period. While this might, at first glance, be a plus, it is also a strategy that comes with risks. The most important is that actually initiating a stock recovery might need a bigger reduction in fisheries mortality than initially estimated. The reason for this is the probable existence of Allee effects (depensation) when stocks are depleted to very low levels. With Allee effects, exploitation would have to be kept at a lower level during the first generation of the recovery and could, if stocks follow their stock recovery trajectories, be increased during the second generation.

Secondly, the need to make significant sacrifices in the form of strong reductions in fisheries mortality would seem less urgent with longer recovery time spans. This would increase the pressure towards a more expansive fishery and thereby also increase the risk of an unsuccessful stock recovery process.

In summary, the risk of an unsuccessful stock recovery increases with the selection of longer recovery time spans. This increased risk is, most importantly, due to longer time spans being accompanied by higher fishing mortalities, meaning that reductions in mortality might be insufficient for stock recovery purposes. Higher mortality levels also mean that the buffer for environmental variation becomes more restricted. We are currently in a period of low marine survival, and one consequence of this has been an unsuccessful initiation of stock recovery since 2017. A selection of more severe restrictions might have ensured that some recovery were taking place despite unfavourable conditions.

5 Alternative strategies for recovery and fishery

Question 4: Alternative strategies for recovery and a sustainable fishery:
a) A strategy based on numbers of early migrating/multi sea winter salmon (numbers counted in given sites)? For instance, by allowing a regular fishery from 1 July, after a certain number of individuals have ascended?
b) A strategy based on the number of ascending 1 SW salmon/diddi the year before?
c) Could a total quota for fish mortality be used as a starting point for regulation of the fisheries? What are the pros and cons of using a fish mortality quota or a seasonal catch quota as management tool?

5.1 Within season counting and fishing

Sonar counting at Polmak could potentially be used as a run size indicator for in-season management of the Tana salmon fisheries. Counted numbers exceeding certain pre-agreed levels at the end of June would then enable starting of regulated salmon fisheries during the latter part of the season (e.g. July-August). Vice versa, if pre-agreed levels were not reached, fisheries would not be opened. A checkpoint in late June would allow estimating the status of multi-sea-winter (MSW) salmon complex and should also give a rough estimate of the one-sea-winter (1SW) salmon run strength.

Adopting this strategy would mean that the exploitation rates of the most valuable MSW salmon would be much lower compared to current (2017) fishing rules and fisheries would generally be targeting smaller 1SW salmon and later running salmon stocks. A detailed fisheries regulation for the possible July-August fisheries would, however, be needed to ensure spawning target attainments throughout the Tana system and for both early and late running stock components. These detailed regulations are beyond the scope of this report.

The usability of the sonar approach is largely connected to environmental conditions. If high floods and/or floating ice occur during the counting period, the reliability of the sonar count will be lower making e.g. mid-season evaluation less functional. These kinds of problems are quite possible and may happen in one out of three years.

In practical terms, the analysis of the sonar data should be performed almost in real-time to allow mid-season evaluation. Extra resources would therefore be needed to analyze the sonar data also during weekends (=costly work) and to compile the data for the in-season evaluation. Secondly, in odd-years large pink salmon migrations will decrease the reliability of the 1SW salmon estimates which will affect the in-season decision making process.

Optimally the sonar counting approach would give some possibilities for limited fisheries in cases where the before season estimates looks poor, but the actual counts indicate better stock situation.

5.2 Forecasting based on number of ascending 1SW salmon in preceding years

The Tana/Teno salmon catch and scale data from 1993 to 2020 show a strong relation between the number of 1SW salmon caught, the number of 2SW salmon caught the year after and the number of 3SW salmon caught two years after (Figure 9). Both regressions are strongly significant (p << 0.001) and explain high proportions of the variance (R^2 = 0.65 for the 2SW and 0.81 for the 3SW).

Consequently, the number of ascending 1SW salmon can be used as a reliable tool when forecasting the number of 2SW and 3SW salmon in the coming years.

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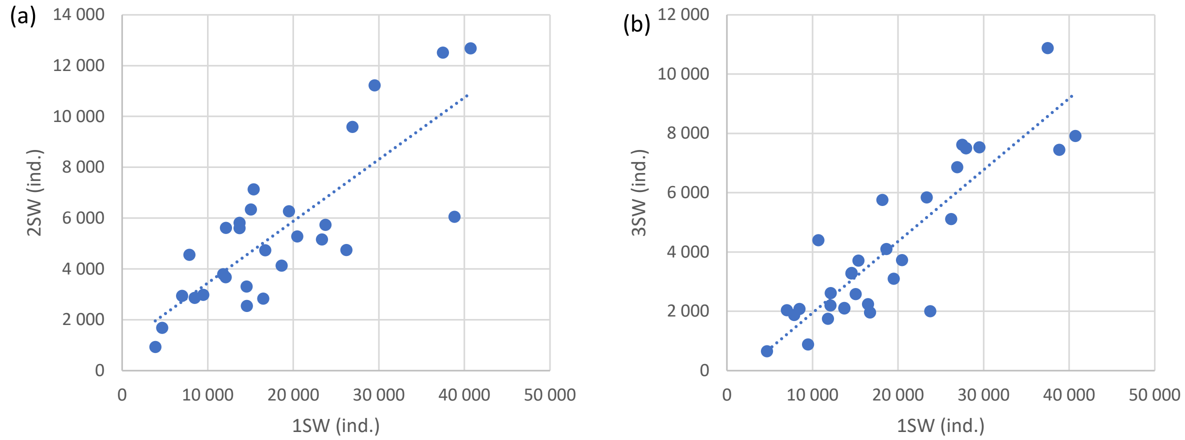

Figure 9. (a) Relation between number of grilse (1SW) salmon and number of 2SW salmon the year after, and (b) relation between number of grilse (1SW) salmon and number of 3SW salmon two years after. Both figures show data from the years 1993-2020. The analysis is based on the Tana/Teno total salmon catch data and scale data, where the sea-age distribution is derived.

5.3 Quota-based fisheries

Quota-based fisheries are often recommended in the discussions surrounding the Tana/Teno fisheries regulations. Quotas can be set in a number of ways, each with their own properties and strengths and weaknesses. We discuss three main approaches separately below.

5.3.1 Total allowed catch

This type of quota can be defined as a proportion of the total salmon run or as a total number of salmon that are allowed to be caught. In order to be useful as a tool, a total quota would have to be calculated before each fishing season, ideally based on a forecasting tool, for instance the forecasting described in chapter 5.2. The actual calculation will have to depend on the choices taken concerning a lower limit for when a salmon fishery can take place in Tana/Teno (discussed in chapter 2) and the recovery time span involved (chapter 4) which ultimately provide a guide for the extent to which spawning stock sizes should be prioritized.

In addition to establishing a protocol for forecasting and calculating a total catch quota, two separate sets of criteria would have to be established concerning 1) how to apportion the quota to different fisherman groups, and 2) how to apportion the quota to stocks within the Tana/Teno stock complex. The latter is important as different stocks within the Tana/Teno have contrasting spawning target attainment with some stocks having more surplus available than other stocks.

The main arguments against a total catch quota concerns the ability to enforce the quota and the uncertainty that arise from this. A catch quota provides an incentive towards keeping the catch hidden and not reporting outside of a limited number of fish. The extent of this would be very hard to estimate and would make it difficult to properly evaluate stock recovery.

5.3.2 Available number of fishing days

Quotas might also be established in terms of fishing days. Traditional salmon management with a defined start and end to the fishing season can be viewed as a variant of this, effectively providing fishermen with a set number of available fishing days. A fishing day quota can also be personalized and further restricted, giving each fisherman a quota of days available to spend within the ordinary fishing season. Ideally, such an allocation of a maximum number of fishing days would be dynamic from year to year, being scaled up or down based on a forecast of the expected run size. So far, however, that kind of flexibility have not been possible due to the way the fishing rules traditionally have been structured.

Practically, a fishing day quota is more easily enforced than a catch quota, for instance by requiring that fishermen are required to register a fishing day before putting their fishing gear into the river.

5.3.3 General and fixed personal quotas, daily and seasonal

A third quota variant is more generally specified personal quotas, which could be in the form of a maximum daily or seasonal catch. Such quotas have been used in many other Norwegian salmon rivers over the last 10-15 years, with mixed experiences. Validations of the efficiency of quotas have shown that these daily or seasonal quotas generally are set too high. Consequently, such quotas end up contributing very little to saving salmon in years with a low pre-fishery abundance, but they are more efficiently saving salmon in years with a high pre-fishery abundance. In other words, personal quotas provide the least help for salmon stocks in the years the stocks need the most help, and the least help for the most depleted stocks.

A further issue with personal quotas is that they introduce uncertainty about the impact of fisheries and the actual catch. For instance, quotas provide an incentive for individuals towards behaviour that ensures they can keep fishing, for instance by keeping their catch hidden and not reporting catch. The ability to enforce a quota is therefore a key factor when evaluating the feasibility of personal quotas as a management tool.

These are all serious problems, which point towards personal quotas being poorly suited as a regulatory tool during the recovery of a severely depleted salmon stock. Experience elsewhere have shown personal quotas to be more useful for keeping a stock at its full-recruited state.

6 Other factors of importance

Question 5: How do factors such as sea survival, predation, climate and habitat changes, and pink salmon affect the stock recovery prospects?

6.1 Sea survival

Salmon survival at sea, that is the proportion of the smolt migration that returns later as adults, is a key factor during stock recovery. For instance, an increase in sea survival would increase the future output of a given spawning stock, thereby strengthening the recovery or providing a larger surplus for exploitation during the recovery. Lowered sea survival on the other hand would decrease the return rate and could, depending on the extent of the unfavourable conditions at sea, completely halt recovery progression if the lowered sea survival reduces the pre-fishery abundance down to levels that eliminate any gains in salmon numbers achieved by reducing exploitation.

Lowered sea survival has been observed for Tana/Teno salmon from 2019 and onwards, as evidenced by the return rate of grilse in 2019-2021 in the Utsjoki monitoring (Figure 13a). The results suggest that the run sizes of grilse (1SW salmon) in 2019-2021 were just 18-40 % of what it would have been if the return rate had stayed at the median level from 2014-2018 (Figure 13b).

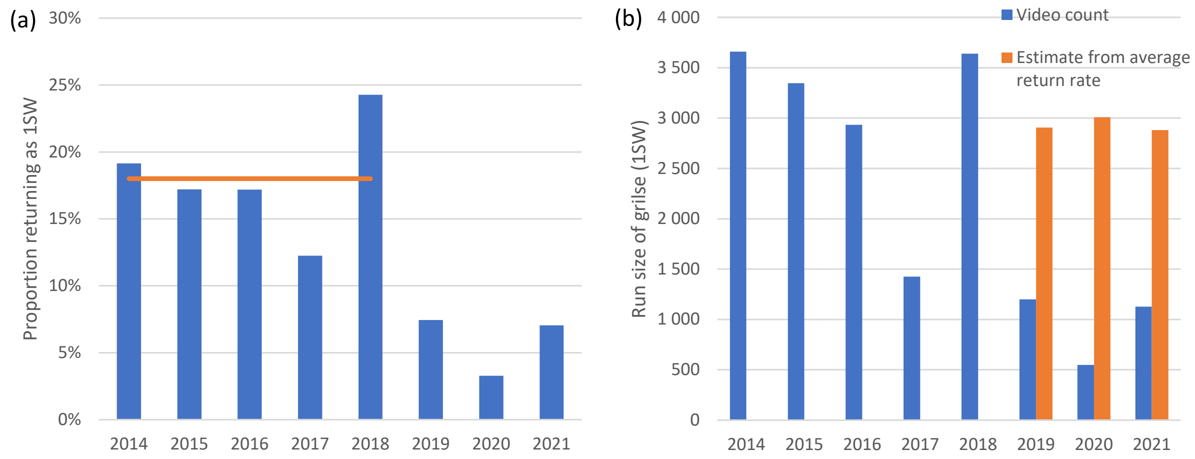

Figure 10. (a) The proportion of the smolt run returning as grilse the year after in Utsjoki 2014-2021. The horizontal orange line represents the average return rate of grilse in 2014-2018. (b) Run size of grilse (1SW salmon) from the video count in Utsjoki 2014-2021 (blue bars) and an estimate of what the grilse run should have been in 2019-2021 if the grilse return rate in those years had been at the average level of the five preceding years (2014-2018) (orange bars).

As a consequence of the recent poor sea survival, fewer salmon than expected have returned to the Tana/Teno river system. Spawning stock sizes therefore continued to be at a low level despite a significant reduction in the overall exploitation with the 2017 agreement (Figure 14). The 2017 agreement did have a positive effect on spawning stock sizes in the sense that the spawning stock sizes in 2017 and onwards ended up being higher than they would have been if the old agreement still had been in place (red vs. orange symbols in Figure 14). However, the 2017 agreement did not result in a sufficiently high mortality reduction to counteract the reduced sea survival, and it was not until the closure in 2021 that we were able to observe a significant spawning stock increase (green symbol in 2021 in Figure 14).

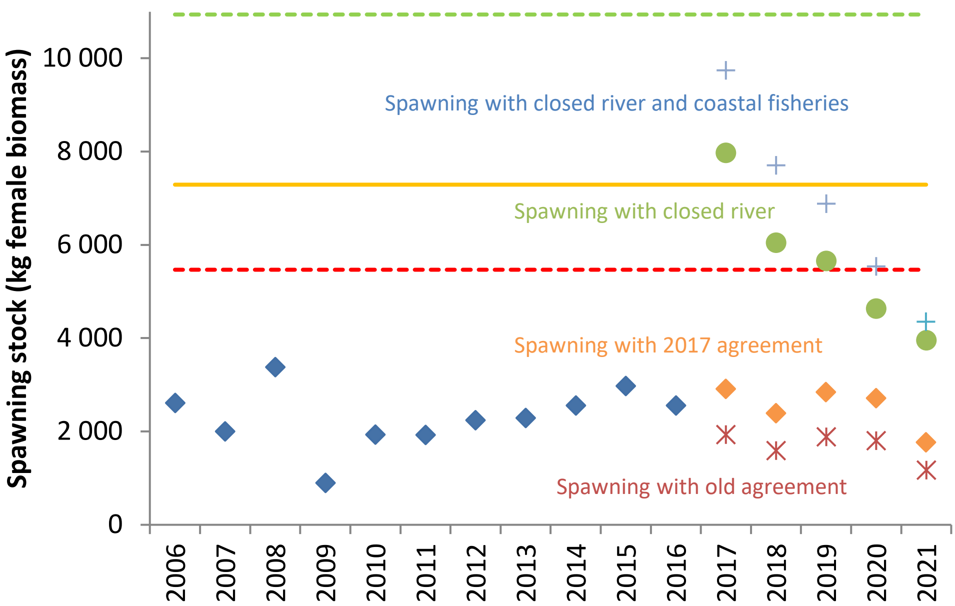

Figure 11. Estimated spawning stocks from Kárášjohka from 2006-2021. Four different scenarios are presented from 2017 and onwards: Red symbols are estimated spawning stocks given a continuation of the old agreement from 1989. Orange symbols are the spawning stocks with the 2017 agreement, including an estimated spawning stock in 2021 if the fisheries had been open. Green symbols show estimated spawning stocks if river fisheries had been completely closed. And light blue show estimated spawning stocks if both coastal and river fisheries had been closed.

We currently do not know what has caused the salmon sea survival to decrease so significantly in periods, which unfortunately makes it difficult to predict when sea conditions might become better. However, keeping track of changes in sea survival is important for recovery purposes, especially in the critical first salmon generation of a recovery period. Poor sea survival results in a low return rate of adults and, consequently, a higher need for restrictions in order to ensure that spawning stocks are kept at the levels required by the recovery trajectory. In turn, higher sea survival might result in a pre-fishery abundance that allows for a limited exploitation level.

6.2 Predation and predator control

Predation is a central ecological mechanism of all ecosystems, including the Tana/Teno river system. A full discussion of predation is outside the scope of this report, but a thorough discussion of the relation between salmon stock recovery and predation that is highly relevant for the issue we are solving in Tana/Teno can be found in a recent report from the Scientific Advisory Council for Salmon Management in Norway (Anon. 2022).

One of the main results from Anon. (2022) is that a full-recruited salmon stock is well-adapted to living with native predators, but as the salmon stock gets depleted, the relative effect of predation increases and when a stock is severely depleted, predation mortality can be a significant stock recovery obstacle.

It might be possible, through systematic and concerted effort, to at least temporarily reduce the number of predators in an area of the river system. However, there is a significant likelihood that the control effort will not produce the overall reduction in salmon mortality that is expected and desired. For instance, a control effort will have ecosystem effects outside simply the interaction between predator and salmon. Reducing the predation rate on salmon will affect interactions between the predator and other fish species, and this might have unpredictable and possibly negative consequences for salmon survival.

The predator control effort itself might also affect the number of salmon directly if salmon are accidentally caught as a bycatch. The extent of a bycatch would depend on the scale and magnitude of the control effort. In assessing how a bycatch affects salmon, especially recovery progress, it is important to factor in that one dead adult salmon far outweighs the importance of one dead juvenile or one dead smolt. In cost-benefit terms, the bycatch would have a definitive negative effect while the long-term benefit of the control effort might be negligible.

Another potential issue that is often overlooked concerns ecosystem productivity. The Tana/Teno river ecosystem has, over millennia, become adapted to a significant annual influx of marine nutrients. This influx has likely been a significant driver of ecosystem productivity. We have disrupted this dynamic through high exploitation rates, greatly reducing the annual input of marine nutrients, thereby reducing the production capacity of the river system. Historically, some (or all) of these losses might have been compensated by nutrients from anthropogenic sources (e.g. agricultural runoff, sewage) but the extent of this compensation has also been significantly reduced over the last couple of decades. Removal of predators and other species would invariably lead to a further depletion of nutrients within the river system. Predators also play an important role in nutrient recycling, a mechanism that would be disrupted through predator control. Activities that reduce ecosystem productivity would not favour the overall salmon production potential in the river system. The needs of a salmon stock recovery goes in the opposite direction, i.e. towards increasing overall productivity, and it is likely that overall salmon recovery could be more significantly improved by measures that increase ecosystem productivity rather than control measures that might decrease productivity.

Based on the above considerations and the more detailed discussions in Anon. (2022), predator control is not a recommended solution for progressing Tana/Teno salmon stock recovery.

6.3 Climate changes including habitat effects

A discussion of current climate trends and expected changes affecting northern rivers and their relevance to salmon have recently been written by the Norwegian scientific advisory council for salmon management (Anon. 2021). We will therefore in this section just briefly point to some specific patterns for Tana/Teno and their prospective relevance for salmon management.

Increasing freshwater temperatures can affect MSW salmon exploitation and kelt survival. The date of ice breakup during the spring has changed over the last century, occurring approximately two weeks earlier now than it did fifty years ago (Niemelä et al. 2009). Early ice breakup is correlated with increased drift net catch and also increased catch of MSW salmon (Niemelä et al. 2009). Earlier ice breakup is also correlated with earlier water temperature increases, which cause kelts to become active earlier, increasing their bycatch vulnerability in drift nets. Increased temperatures also mean that kelts are less likely to survive being caught and released. On the other hand, less violent ice breakups have likely decreased kelt mortality during the breakup.

For the smolts, earlier ice breakup and earlier temperature increases could result in earlier migration time, an overall trend shown in the entire range of Atlantic salmon (Otero et al. 2014). This has the potential to be problematic. The smolt migration timing has, over several millennia, been selected towards entering the Tana fjord at a time when food availability and survival is at its best. Earlier migration could therefore mean entering seawater at a suboptimal time, lessening growth and survival.

Locals have pointed to less severe ice breakups as a factor driving habitat changes in the Tana/Teno main stem. Less violent ice breakups mean less scouring of the river substratum, a build-up of sand and degradation of habitat quality in potential spawning areas. Further work is needed to quantify the extent of any such habitat changes, but a decade-old extensive habitat mapping throughout the main stem could be valuable, effectively providing a historic reference point that could be used to quantify changes today and in the coming years.

6.4 Pink salmon

The recent increase in pink salmon distribution and abundance in the North Atlantic area has been especially pronounced in the northernmost areas in Finnmark, including the Tana system. Concerns has been raised about the impact of the sudden increase in abundance of this alien species to the native salmonid fishes and Atlantic salmon in particular. However, little information is available on observed changes in salmon populations that could be directly attributed to increase in pink salmon abundance. Such situations should be found especially in the Russian North-West, Kola Peninsula and White Sea basin, where pink salmon has been present in Atlantic salmon rivers for several decades, but very little evidence, if any, of negative impacts on Atlantic salmon is available. However, the recent assessment of risk from an increase of pink salmon in Norway (VKM 2020) listed several potential direct and indirect factors that the new situation with pink salmon abundance could potentially bring along and cause problems for native river ecosystems and their fish species.

In Northern Norway, effective removal fisheries on pink salmon have been organized in several rivers since 2017, and discussions and plans to start mass removal fishing at the Tana are underway. It should be noted that any significant effort to reduce the number of migrating pinks would also negatively affect the salmon. For instance, some salmon will be caught in removal efforts that involve fishing, for instance with the suggested removal efforts with coastal fishing gear. Fish traps and migration barriers also have potential effects for all native migratory fish. There are experiences from different countries and areas (personal communication and unpublished data from e.g. Denmark, Scotland, Finland (Baltic salmon)) indicating potential negative effects of intercepting salmon migration early in the season in lower parts of rivers that can cause changes in migration behaviour, delays in proceeding upstream, or even fallbacks, i.e. fish turning downstream with either delayed return or no return at all with possible straying to other rivers.

Consequently, it is very likely that mass removal of pink salmon will cause at least some collateral mortality for Atlantic salmon and therefore have consequences on Tana/Teno salmon stock recovery and the prospects of a limited reopening of fisheries during the recovery. The likely negative effects will decrease the number of adult salmon available for spawning in odd years, thus also reducing the possibilities of fishing. The latter will especially be the case in periods of low sea survival.

7 Recommended recovery path combining forecasting and risk

As discussed in previous chapters, in order to have a successful stock recovery, spawning stock sizes in coming years need to be kept at a higher level than the spawning stocks in the preceding years. This is particularly important for the first step or generation of the recovery due to the severely depleted levels of important stocks within the Tana/Teno stock complex. Here is the first risk that must be accounted for: *Failing to sufficiently reduce mortality will lead to an unsuccessful recovery*.

A practical example of this risk can be seen in Figure 10. The 2017 agreement aimed at a 30 % reduction in fisheries mortality in order to start a recovery. But, as can be seen in Figure 10, the annual spawning stock size was relatively similar in the years before and after the 2017 agreement. Accordingly, the 30 % reduction in mortality was not sufficient to counter a situation with severely reduced sea survival. The main lesson then is that a recovery plan based on a general reduction in fisheries is not sufficiently robust to tackle increased mortality from other sources. Clearly a more robust approach is needed.

The spawning stock situation changed in 2021 after the river fisheries were completely closed and coastal fisheries significantly reduced. The relatively stable low average spawning stock before 2021 is illustrated with a horizontal red line covering 2013-2020 in Figure 10. The 2021 spawning stock represented a significant increase from the 2013-2020 baseline level and with the continuation of the fisheries ban, the 2022 spawning stock is expected to be similar to 2021 or even a bit higher. The increase from the red to the orange line in Figure 10 is, in essence, the best that could be achieved in a situation with low sea survival levels over the last three years.

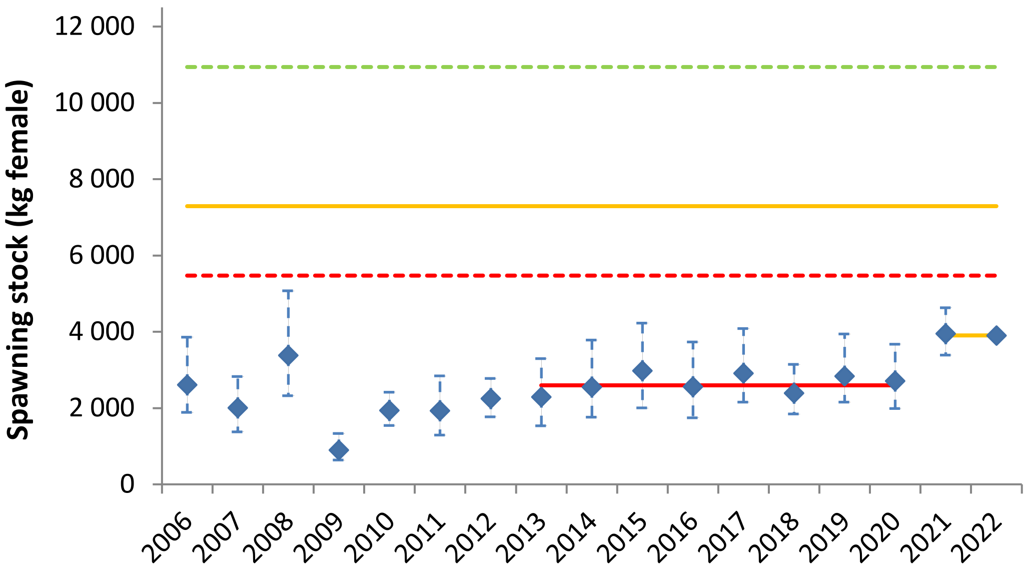

Figure 12. The estimated spawning stock in Kárášjohka in 2006-2021 and a forecast of the 2022 spawning stock. The horizontal red solid line shows the average spawning stock of 2013-2020. The orange solid line the average for 2021-2022 and represents the first two years of a first generation step in a recovery trajectory for Kárášjohka. The next increasing step of the trajectory, which would be based on the 2021 increase in spawning, can be expected after one salmon generation (7-8 years as defined in chapter 4), i.e. in 2028-2029.

The 2021-2022 increase can be viewed as the first two years of a first generation step in the recovery trajectory of Kárášjohka. The spawning stock level illustrated by the horizontal line through 2021-2022 in Figure 10 can then serve as a minimum target for the remaining 5-6 years of this first recovery generation. This means that any fishing in the coming years should not reduce the spawning stock below the level indicated by the orange line in Figure 10. Any discussions about fishing in the coming years thus have to treat the 2021-2022 spawning stock as a minimum baseline, and any salmon fishing opportunity in the coming years should only happen if a surplus is expected above the orange line. So for a given year, the pre-fishery abundance of a stock has to be higher than the baseline spawning stock size, and the difference between the pre-fishery abundance and the baseline spawning stock would represent the surplus available for fishery. Again there is a risk involved: As fisheries are more and more opened, the risk of catching too many salmon increases. No fishing represents minimal risk with the risk gradually increasing with increasing scope of the fisheries. This balance is illustrated in Figure 11.

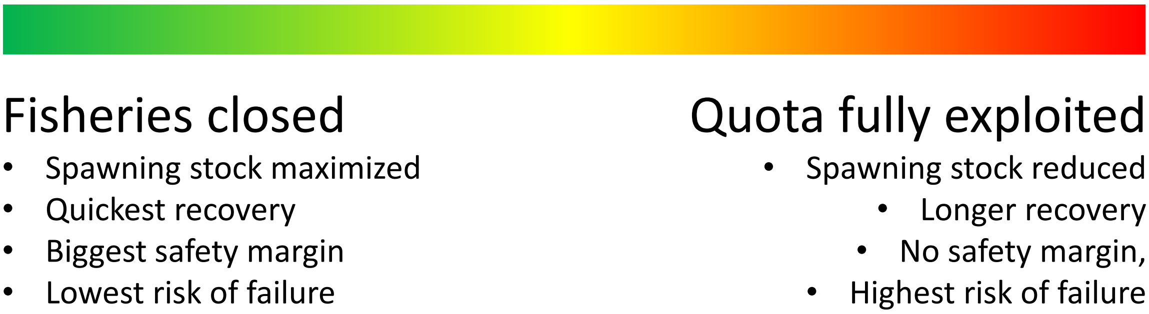

Figure 13. Conceptual visualization of the risk and recovery consequences of moving from closed fisheries towards increasing exploitation of catch quotas. Closed fisheries represent the situation with least risk and quickest recovery, whilst allowing for increased exploitation, to the point where quotas are fully exploited, will increase risk of failure and prolong the recovery time.

As demonstrated in chapter 5.2, the number of grilse in the preceding two years can be used to provide a forecast of MSW salmon in a subsequent year. It is therefore possible to have stock-specific predicted pre-fishery abundances included in the annual status report. The difference between a forecasted pre-fishery abundance and the desired spawning stock target for the first recovery generation illustrated in 2021 and 2022 in Figure 10 could then serve as a stock-specific total quota for the coming year. To specifically illustrate, the 2021-2022 Kárášjohka average spawning stock in Figure 10 is 3 900 kg. If the forecast for 2023 indicated a female pre-fishery biomass of 5 000 kg, a quota of a maximum of 1 100 kg might then be available for fisheries. In practical terms, there are several risk factors associated with this quota estimate. Firstly, the performance of a predictive model has to be assessed to evaluate the extent of deviation between the predicted quota and the actual run. Secondly, a risk assessment must also be performed on the possibility that a restricted fishery might overexploit the quota. Overestimating the quota and underestimating the exploitation might both lead to significant negative consequences for the stock recovery process.

The performance of the predictive approach can be evaluated with real data (scale reading and catch statistics) from our stock assessment in 2006-2021. In Figure 12, a simple model, based on the estimated number of grilse in one year and the numbers of 2- and 3SW salmon in preceding years, was used to forecast the pre-fishery abundance (blue bars). This forecast can then be compared to the actual PFA estimated from the annual monitoring (orange bars). Overall, the model performs remarkably well in the average years. However, the model performs less well in some years, namely the years that deviate from the average, for instance years with sea survival that was better or worse than the average sea survival. The model underestimates the pre-fishery abundance in years with higher than average sea survival, most notably 2007 and 2008. For stock recovery purposes, that is not a problem as fishing less than allowed for does not affect the likelihood of a successful stock recovery. The significant issue arises in the years with lower than average sea survival, for instance 2019-2021.

Here, the model significantly overestimates the PFA, which then would lead to a catch quota that would reduce spawning stocks significantly below the level set by the recovery plan.

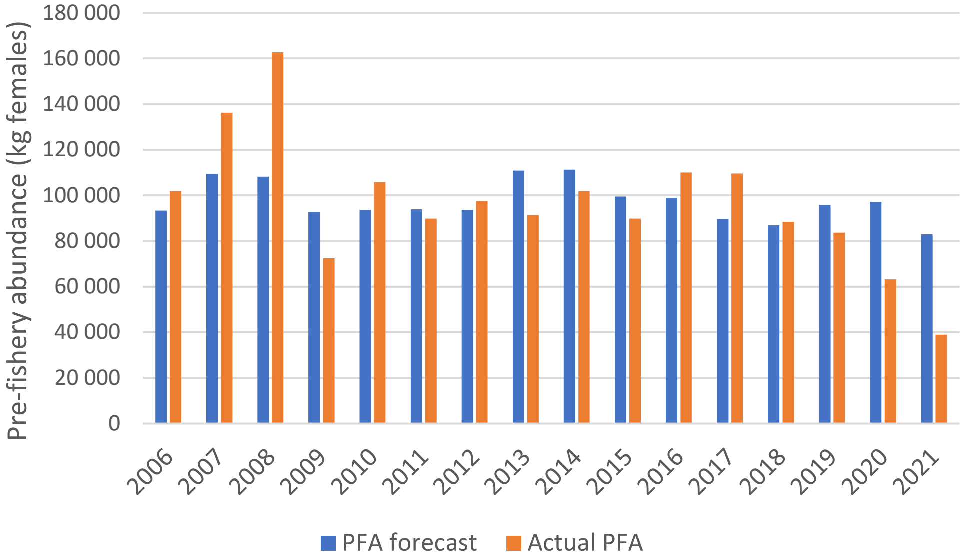

Figure 14. A forecast of the pre-fishery abundance (PFA) based on the run size of 1SW salmon in preceding years (blue bars) and the actual PFA estimated from monitoring data (orange bars).

In summary, the model performs well in most years, but fails to provide the desired level of protection in the years with the most vulnerable stock situation. It is possible to remedy this, for instance by including a factor that can be used to adjust model parameters in periods with expected lower than average sea survival. For instance, observing poor sea survival one year should result in a reduced forecast for the coming year. We would still face the danger of single-year overexploitation due to sudden onset of poor sea survival (despite of a lot of research going into factors affecting salmon sea survival, we are still nowhere near being able to predict when periods of poor sea survival might occur), but this danger can at least partly be remedied through the use of in-season monitoring data, e.g. from the Polmak sonar counts.

There are additional questions that need to be solved after establishing baseline stock-specific quotas consisting of surplus females available for exploitation. Firstly is the question of when and where this quota should be caught. Again, a risk assessment needs to be done, especially concerning the question to what extent the quota should be taken in the coastal and main stem mixed-stock fisheries. There is a significantly higher level of risk associated with mixed-stock fisheries compared to for instance tributary-specific single-stock fisheries. The stock of origin of salmon caught in the mixed-stock fisheries are largely unknown, with the risk that some stocks might avoid exploitation while others are overexploited.

Secondly, the viability of forecast-based quotas as a management tool in a stock recovery process hinges on the extent to which the countries are able to enforce the quotas. The importance of this enforcement, to ensure that quotas are not overfished, will be especially critical during the first generation of the recovery process when the stocks are most depleted. During a second generation, spawning stock target attainment will be higher, stocks will be less affected by Allee-effects and able to sustain a higher exploitation level. However, a careful approach will still be needed, treating the second generation spawning stock target as a minimum baseline and dynamically change the fisheries through the above forecast-based approach if, for instance, new periods of lowered sea survival were to occur.

8 A recommended monitoring and research framework for the Tana/Teno stock recovery process

The basic annual monitoring needs during a stock recovery phase in Tana/Teno would be relatively well covered through the continuation of the currently employed spatially distributed fish counting methods. The combination of main stem and tributary counting provides the basic data needed to make spawning stock and PFA estimates for different parts of the Tana/Teno river system.

There are, however, improvements that can be made to the analytical side that would significantly improve how we handle the recovery phase. We recommend prioritizing the establishment of a new modelling method, effectively combining the current status evaluation approach with the Bayesian approach of the Baltic stock assessment.

A prerequisite of this modelling approach is the establishment of an updated genetic baseline based on a comprehensive set of SNP markers. The previously used genetic baseline for identification of population of origin in mixed-stock fishery date back to mid-2000s and early 2010s and used a limited set of microsatellite markers. Whilst functional at its time, the microsatellite approach has largely been abandoned and replaced by SNPs, a methodology that allow for a higher number of markers which increase the statistical power of the stock identification methodology. The new SNP baseline has mostly been completed, but some resources are still needed to complete the baseline (mainly to ensure sufficient spatial coverage) and assess the baseline performance.

A second important part of the data going into the new model is the individual scale data from the mixed-stock fisheries of the Tana/Teno main stem from the post-2017 years, that is the years after the significant change in fisheries management following the Tana/Teno fisheries agreement of 2017. Individual stock identification, life history information from scale reading, catch place and time and gear, fish size and sex would all be important information going into the modelling data set.

A Bayesian population model should then be developed for evaluating stock status, recovery trajectories, and how the likelihood of recovery success is affected by differing levels of exploitation. This would improve the evaluation of all parts of the river system, in particular those populations that have very limited monitoring data. The current stock status evaluation is missing the real options for forecasting, and a full life cycle model (following the examples from e.g. Baltic salmon stock assessment) would provide a rigorous quantitative options for predictions and evaluations of alternative future scenarios.

Bayesian methods could also be used for more reliable estimation of smolt to adult survival, mainly based on video data from Utsjoki. Estimation of accounting for some uncertainties in smolt counts have already been developed (Pulkkinen *et al*. 2020) and the different estimates and data sets should be combined into a probabilistic modelling framework for improved survival estimates. Marine survival is currently one of the key parameters affecting the recovery potential of Tana salmon (see chapter 6.1).

A key strength of the above modelling approach is obtaining a probability-based tool that flexibly can have knowledge from different sources as input, and in return provide the probability of success based on different scenarios. For instance the probability of successful recovery under different levels of exploitation against a range of conditions at sea. We should also be able to parameterize the model in a way that enables estimation of how different fishing rules would affect exploitation rates on a stock-specific basis.

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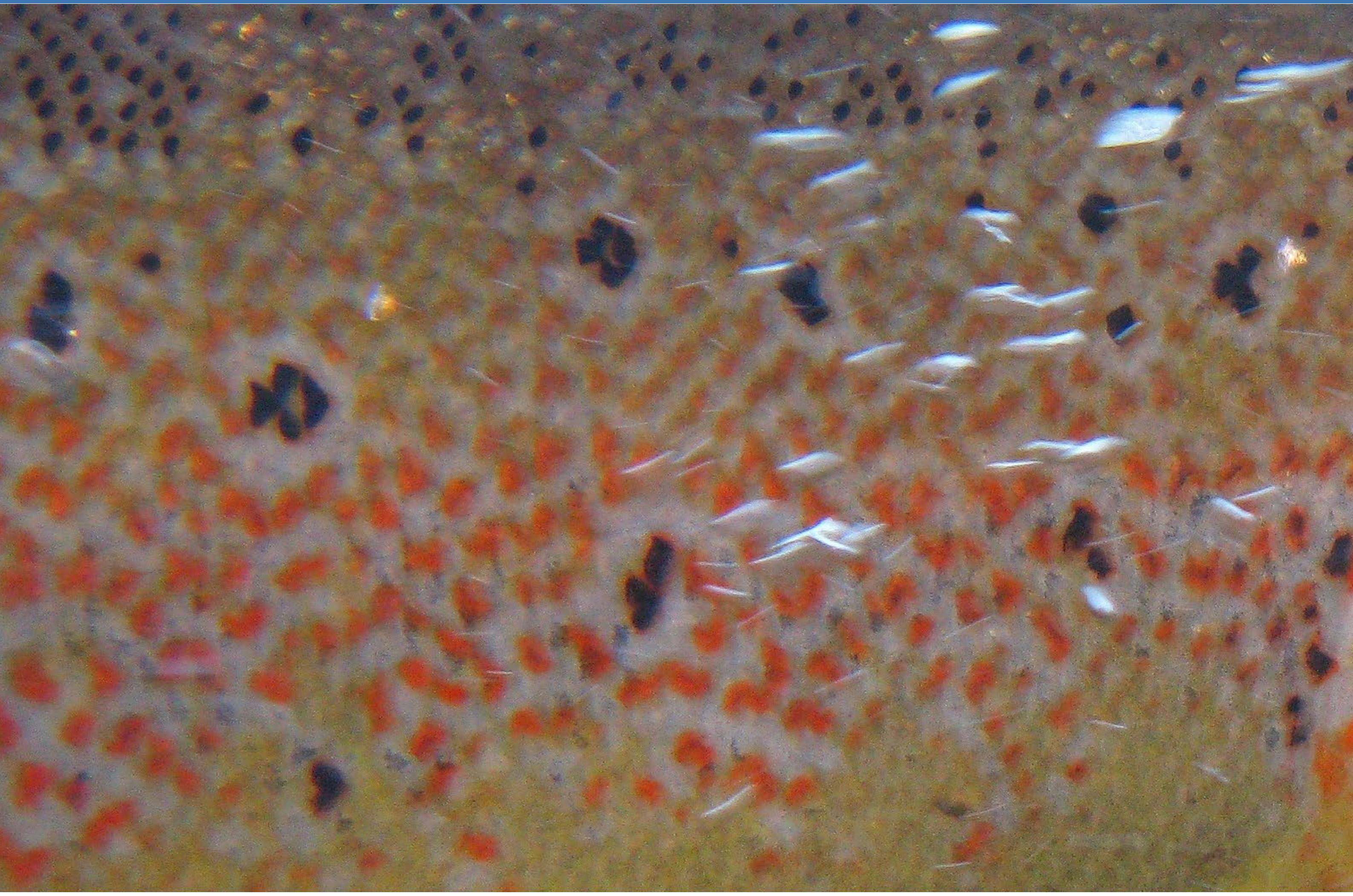

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