Abstract

According to governmental plans, Norway faces huge expansions in the production of farmed Atlantic salmon. However, it is municipalities that designate coastal areas to aquaculture activities and their motivation depends on net benefits at municipal level from such use. Yet, there is little empirical evidence on costs and benefits of using coastal areas to aquaculture activities. We set up a cost-benefit analysis of salmon farming as seen from a municipal perspective. On the benefit side we count consumer and producer surplus of increased aquaculture production in the region, and the region's share of the national rent in aquaculture received as transfers from the national Aquaculture Fund. Costs are the opportunity cost of the land (sea) use, measured by households' willingness to pay to avoid aquaculture expansion, using data from a choice experiment. We find that parts of the producer surplus have to contribute to the regional economy for the NPV to be positive for a region.

1 Introduction

Marine aquaculture is an expanding industry worldwide (FAO 2018). It provides food for humans and generate jobs and income to coastal communities (Béné et al. 2016), but can have negative effects on marine habitats and wildlife (Taranger et al. 2014) and human coastal and marine stakeholders (Young et al. 2019). While studies find that large ocean areas are suitable for expanding marine aquaculture (Troell et al. 2017), the benefits and costs or risks of establishing or expanding aquaculture should be carefully assessed and weighed up against each other. It is the aim of this paper to implement such an analysis for a region encompassing five municipalities in Norway.

The production of 1.24 million tons of Atlantic salmon in 2017 makes Norway a world leader in marine finfish aquaculture production (FAO 2018; 29), This was nearly a tripling compared to year 2000 and more than an eight-fold increase since 1990 (Statistics Norway 2019). On the other hand, this was about the same as the production in 2012.

Increases in aquaculture production requires control with environmental and sanitary conditions. Disease outbreaks have given serious setbacks to aquaculture production both in Chile (Quiñones et al. 2019) and Scotland (Ellis et al. 2016), the two largest producers of farmed Atlantic salmon after Norway (FAO 2018). In Norway, production costs have increased substantially recent years due to problems with salmon sea-lice (Lepeophtheirus salmonisn) (Iversen et al. 2017), and the problems with handling the lice is one important reason for limitation of new salmon aquaculture licences from 2013 (Hersoug et al. 2019).

In Norway, companies involved in aquaculture production needs a license, which consists of two parts. The first part is the right to hold a certain amount of fish of a certain species. For salmon, the number of licenses is restricted, and new licenses or increased Maximum Total

Biomass (MTB) per license are issued by the government only every second year. The second part of the license is the right to farm on a specific locality. This requires permissions from regional environmental and veterinarian authorities, and the locality must also be in accordance with municipal coastal zone plans, or the municipality must grant an exemption from the coastal zone plan. Hence the municipalities' designation of area to aquaculture activities in coastal plans is crucial for a salmon company´s access to production locations, and the number of available locations may limit the industry's ability to expand production. The municipalities' motivation for dedicating coastal areas to aquaculture activities depends on expected net benefits from such use (Isaksen et al. 2012).

Although Norway's population is relatively small and the coastline very long, this does not mean that assigning coastal space to aquaculture has no opportunity cost. The coast is widely used for recreational and subsistence activities (Jentoft and Buanes, 2005). The coast is also extensively used for commercial fish harvesting (Young et al., 2019).

While salmon farming in Norway started, and is still dominantly taking place in the south, expansion is mainly expected in Arctic Norway (Ministry of Trade, Industry and Fisheries, 2015). One reason is the assumption that it is easier to control the sea-lice problem in colder sea temperatures. Another reason is the far lower density of aquaculture farms in the north, despite the fact that Arctic Norway's share of national production of farmed salmon has grown from 28 % to 44 % during 1997-2017 (Statistics Norway 2019).

According to a survey among inhabitants of Arctic Norway, they are on average positive to seeing (more) fish farms along the coast (Aanesen et al., 2018). However, in the largest city, Tromsø, the population is willing to pay to avoid seeing (more) aquaculture (op cit). In a qualitative survey with respondents from Tromsø and the Lofoten islands, people indicate that there are limits to how much development should be allowed in the coastal zone (Aanesen et al., 2017). This perspective is independent of whether they are positive or negative to aquaculture expansions in the region.

This paper compares costs and benefits from increased salmon aquaculture activities on an inter-municipal level in Norway. It is a case study based on a coastal area plan for five municipalities in the northern part of Troms county in Arctic Norway, henceforth the Tromsø-region, as it includes Tromsø, the largest city in Arctic Norway. The original plan suggested 18 new areas for salmon farming and the extension of two existing aquaculture areas. After public hearings and political decisions in the municipalities, 5 of the areas were withdrawn and 1 is still disputed. Hence, the plan currently includes 12 new areas and 2 extended areas for aquaculture activities. Figure 1 shows a map of the region with aquaculture localities before the implementation of the plan.

Figure 1 about here:

Map of the Tromsø-region with approved aquaculture locations per 3 January 2018.

Source: Directorate of Fisheries' map tool (https://kart.fiskeridir.no/akva).

The paper proceeds as follows: Sections 2 and 3 presents methods, materials, and an econometric model respectively, section 4 presents results and section 5 discusses results and concludes.

2 Materials and methods

2.1 Methods

We follow Neiland et al. (1991) when it comes to a framework for assessing impacts of aquaculture expansions, which encompasses the following stages:

Stage 1 Definition of the boundary of the analysis

The analysis is seen from a municipal perspective, implying that redistributional effects that cancel out at national level may be included in the net present value at the regional level. Based on an inter-municipal coastal plan for the Tromsø region, we monetize benefits and costs as far as possible. Benefits and costs not possible to monetize are treated qualitatively.

Stage 2 Identification of costs and benefits

Following Neiland et al (1991), social and economic costs and benefits of aquaculture activities on a national level are largely as given in table 1.

Table 1 about here

Identification of social and economic benefits and costs of aquaculture at national level

Source: Neiland et al. (1991)

In this analysis benefits are counted as the aggregate of the region's share of producer and consumer surplus from the increase in commercial salmon farming.

Although Norway is the world's largest producer of farmed Atlantic salmon, prices are set globally, and Norwegian companies are mainly price takers in the market (Landazuri-Tveteraas et al., 2018). In 2016 the production of salmon in the Tromsø-region was 1.1% of the Norwegian production of salmon. Thus, we assume insignificant changes in the price of salmon to consumers due to growth in production in the Tromsø region, implying no change in consumer surplus.

In recent years, the farmed salmon industry in Norway has been very profitable (Misund and Nygård, 2018, Asche and Sikveland, 2018). To acquire part of the rent, the authorities have demanded significant fees from the industry for new licenses (Hersoug et al., 2019). Auctioning has been seen as an "objective" allocation mechanism (Meld. St. 16 2014-15). The fees acquired through such auctions have since 2017 been channeled into an "Aquaculture fund". The fund, in practice, redistributes parts of the surplus of aquaculture production from producers to municipalities, which receive transfers from the fund based on existing and newly awarded localities for aquaculture (Ministry of Trade, Industry and Fisheries, 2017). Hence, the producer surplus of aquaculture production encompasses the net present value to a company of acquiring and operating a license, and for a municipality it encompasses the share of the license fee transferred to the region.

As social costs of aquaculture expansions we use opportunity costs for coastal area when used by local inhabitants for recreational activities and other uses. A stated preference survey among the North-Norwegian population contributes data to estimate this opportunity cost.

Conservation of social structure and improved infrastructure in rural areas are benefits relevant at a municipal regional level, but it is difficult to monetize such effects, and they will therefore be treated qualitatively in this analysis. Also, economic data on specific environmental damages caused by aquaculture is scarce for this region. When it comes to negative effects on other usages, we assume that this is included in peoples' stated willingness to pay to avoid aquaculture expansion.

Stage 3 *Valuation of costs and benefits in two stages:*

a) Financial evaluation
b) Conversion of financial to economic values

To obtain the values to be used in the benefit cost analysis, one must correct market prices for taxes and subsidies and finding shadow prices for benefits and costs with no market price. For example, market prices must be stripped of VAT and other fiscal taxes not reflecting costs to society of the production.

Stage 4 *Comparison of economic costs and benefits over time and under various alternative scenarios to assess the net economic benefit returned.*

To take into account uncertainties in both costs and benefits, we use 27 scenarios when estimating the net present value of aquaculture expansion in the Tromsø-region. Due to considerable ecological uncertainty regarding future aquaculture expansion we use a 10-year perspective. Economic factors of considerable uncertainty are the payments to the region from the Aquaculture Fund, the share of the producer surplus from the new licenses that will accrue to the region, and the size of the opportunity cost for use of coastal area.

2.2 Data and assumptions

The current regime for aquaculture expansion in Norway is denoted “the traffic light system” (Meld. St. 16 2014-15) and implies that production of farmed salmon can only expand in so-called green production areas, i.e. areas with low salmon-lice induced mortality on wild salmon stocks (Torrisen et al., 2013). For the 2017-2019 period the Tromsø-region belongs to a green production area (production area 11) (Ministry of trade, Industry and Fisheries, 2017b), which means that production capacity may increase with up to 6% of existing capacity every second year (Ministry of Trade, Industry and Fisheries, 2017a). In 2018 the production capacity in area 11, to which the Tromsø-region belongs, increased by 5.7%. At the end of 2017, total national license capacity was 812,542 tons, distributed on 976 licenses (Directorate of Fisheries database). The standard salmon farming license in production area 11 has been 945 tons maximum total biomass (MTB). This means that total biomass of fish cannot exceed this number at any time. In production areas further south (production areas 1-9) the standard license size has been 780 tons.

Table 2 shows the assumptions we use regarding total expansion in production capacity in the region, what this corresponds to in terms of standard licenses, and how much of the producer surplus will accrue to the region. Regarding the latter, there are two ways to dispose of a producer surplus; 1) distribute it as dividend to the company owners, 2) reinvest it in the company. Producer surplus generated by locally owned companies will contribute to the local economy in both ways, whereas companies fully owned by interest outside the region will only contribute via 2), and then only for the parts of the company that operates within the region. Currently (February 2019), only one of 7 aquaculture companies operating in the region has regional ownership. We don’t know whether or how many new licenses this company will acquire in the future. Also, we don’t know how producer surplus generated by the companies operating in the region will be distributed on 1) and 2) in the future. Hence, to simplify, we assume that a share of the total number of new licenses issued in the region accrue to local owners, such that the whole producer surplus is counted as benefit to the region. For those licenses not accruing to local owners we assume that nothing of the producer surplus remains in the region. Table 2 shows that we use a baseline scenario where no new licenses are acquired locally, i.e. that nothing of the producer surplus remains in the region. This was the case in the 2018 auction. In the medium scenario additional producer surplus corresponding to 3 licenses acquired by a locally owned company benefits the region during the decade 2019-2028. In the high scenario additional producer surplus corresponding to altogether 6 new licenses benefits the region during this period. The rationale for the medium scenario is expansions in the locally owned company, while in the high scenario new, locally owned companies are established or locally owned companies take over existing companies operating in the region.

We use a 10-year perspective for the analysis. There are a few arguments that support this assumption. First, after 10 years in operation, the 12 new localities set aside for aquaculture production in the coastal plan from 2015 will probably have been set in production. Furthermore, with increasing biomass of farmed salmon in this production area the risk that it no longer remains green, and thus can continue to expand, reduces.

Table 2 about here.

Growth path for aquaculture production in the Tromsø-region, 2019-2028

The Aquaculture fund channels 80 % of the aquaculture license fees back to municipalities and county municipalities (Ministry of Trade, Industry and Fisheries, 2016). All municipalities with localities share 60 of these 80 %, according to their relative share of locality production capacity, while 10 of the 80 % are similarly shared among the counties where the localities are. The remaining 10% is divided among municipalities with newly approved localities. The income to the fund depends on the capacity increase and the size of the license fees. The traffic-light system has so far implied a national capacity growth of 1.45% per year for 2018-19. However, if the production capacity in the red production areas must be reduced by 6% in 2019, net capacity increase will be only 0.73% per year for 2018-19.

Total income from license fees depends on the expected annual national capacity growth. We use three annual national growth rate scenarios; 0.5%, 1.0 % and 1.5%. The fee paid for a "standard license" has varied significantly over the last 3-4 years. In 2015, some licenses were sold at a fixed price of 1.25 million USD,[1] while those auctioned in 2015 on average achieved a price of 6.88 million USD. The fixed price for additional capacity for existing farms in green production areas in 2018 was 14,063 USD/ton[2], corresponding to 11.0 million USD for a license of 780 tons and 13.3 million USD for a 945 ton license. However, at the auction in June 2018 production capacity was sold for an average price equal to 19.0 million USD per 780 ton license, and 23 million USD per 945 ton license in the Tromsø-region. Table A1 in the appendix reports estimated transfers from the Fund to the Tromsø-region depending on assumptions on capacity growth rate and license fee.

People's willingness to pay to avoid aquaculture expansion along the coast of the Tromsø-region is very heterogeneous, yielding large confidence intervals. To take into account this uncertainty, we use the upper and lower limit of the 85% confidence interval in addition to

[1] Exchange rate used is 8.50 NOK/USD
[2] 120,000 NOK/ton. Exchange rate used: 8.50 NOK/USD.

average WTP. Table A3 in the appendix report the total WTP of the regional population to avoid aquaculture expansions.

The Norwegian Directorate of Fisheries provide data on aquaculture production at the county level. The database includes number of fish farms, total number of employees, production in tons, and financial values on revenue, costs and profits. The data are registry-based, except the financial information, which is based on region-specific samples, and shows regional averages across surveyed firms. Data on employment, sales revenues, costs and profits in the aquaculture industry on national and regional level are taken from this database.

2.3 Empirical case

The Tromsø-region is part of Troms county, which is the third largest county in Norway when it comes to number of localities, number of companies and employees within aquaculture of salmonid fish for consumption. It is the fourth largest in terms of number of licenses (Norwegian Directorate of Fisheries. Aquaculture statistics)

Of the 104 licenses issued in Troms county in 2017, 32 were issued and used at localities in the Tromsø-region. Each license yielded an annual production of about 1350 tons.[3] Of the 117 cleared localities in Troms county, 26 localities were in the Tromsø-region. Hence, while there are 1.125 localities per license in Troms county, there are only 0.81 localities per license in the Tromsø-region. The reason is that most localities have approved capacity to

[3] Average production per license for companies located in Troms and Finnmark counties during 2008-2017.

operate several licenses simultaneously. Hence, this indicates a need for more localities in the Tromsø-region, which in turn support an assumption that new localities for aquaculture production will quickly come into use if licenses are at hand.

While parts of the Tromsø-region are well developed with a diversified economy, there are also less developed parts, in which aquaculture expansion would be a significant contribution to economic activities. Unemployment rates are in general low throughout the region, but these less developed parts of the region also face continuous emigration of young people.

3 Econometric model for stated preferences for aquaculture expansion in the Tromsø-region

Parallel with the development of the coastal plan for the Tromsø-region, a survey among households in Arctic Norway, encompassing the three northernmost counties Nordland, Troms and Finnmark, was carried out to collect data on the population's use and valuation of coastal areas for recreational activities (Aanesen et al, 2018). The survey encompassed nine choice cards, where the respondents were asked to make choices trading off environmental aspects (attributes) like waste on the beaches, recreational harvests and visual intrusion, against economic aspects like new jobs. The cards also included a payment for choosing higher values on the environmental aspects. Figure A1 in the appendix shows an example of a choice card. The design of the cards was based on 2 focus groups with representatives of the public and interviews with commercial units within aquaculture and marine fishing tourism. These two industries were chosen as examples of future industrial expansion in the coastal zone based on interviews with decision makers responsible for economic development in the county administrations. A random utility model provides the foundation for converting the respondents' choices on the cards to willingness-to-pay estimates for the attributes.

Random utility theory suggests that the utility a person receives from a good can be divided into a determined part, which can be explained by the researcher, and a random part (McFadden, 1974). The utility to person *n* of choosing alternative *j* in choice situation *t* is thus given by;

$$U_{njt} = b * X_{njt} + e_{njt} \quad (1)$$

where X_{njt} is a vector of attributes specifying the good, b is a vector of estimated coefficients for the attributes, and e_{njt} is an independently and identically distributed (IID) extreme value (usually Gumbel) distributed error term.

It is reasonable to assume that respondents differ in their preferences for the attributes. Formally, we take preference heterogeneity into consideration by letting the vector of attribute coefficients, $\boldsymbol{b}$, be respondent dependent, i.e. $\boldsymbol{b_n}$, with a distribution specified by the researcher (Hensher et al., 2007). Hence,

$$b_n = b + L\mu \quad (2)$$

where $\boldsymbol{b}$ is the mean estimated coefficient for the specified attribute, L is a lower-triangular Choleski factor of V, the covariance matrix, and μ is a vector of independent standard normal deviates. Thus, (2) is now given by

$$U_{njt} = b_n * X_{njt} + e_{njt} \quad (3)$$

While the model given by (1) is the multinomial logit model (MNL), the model given by (3) is the mixed MNL model. When given a series of alternatives, described by the levels of the attributes, *X*, a person will choose alternative *j* to alternative *k* when $U_{njt} > U_{nkt}$, $\forall\ k \neq j$. Given the stochastic nature of the utility function, the probability that respondent *n* will choose alternative *j* in choice situation *t* is;

$$P_{njt} = pr\left(b_n * X_{njt} + e_{njt} > b_n + X_{nkt} + e_{nkt}\right), \forall k \neq j \qquad (4)$$

With IID extreme value error terms, (4) reduces to a rather simple expression for conditional choice probability for choosing one specific alternative (Train, 2009, p 36), and taking the product over all choice situations yields the expression for the probability of a respondent's observed sequence of choices. The integral of this sequence yields the unconditional probability of observing a sequence of choices. This integral cannot be calculated analytically and is instead approximated by a simulation over randomly chosen values of ***b***. The estimated parameters are those which maximize the simulated log-likelihood function.

The estimated vector of parameters, b_n, is expressed in utility units. Estimation of willingness to pay (WTP) is our key objective for this analysis, and therefore we keep the cost-attribute parameter fixed. The distribution of the WTP is far more complex when the cost-attribute parameter varies as well (Train, 2009, p. 309). In order to derive willingness-to-pay (WTP) in monetary units we take the ratio of each of the non-cost attribute coefficients and the cost-attribute coefficient. Calculating marginal WTPs under mixed MNL with non-random cost attribute, there is no need to take into account coefficient correlations. Hence, the marginal unconditional WTP for an attribute is given by;

$$WTP_h = \frac{b_h}{b_C}, \forall h \neq C \qquad (5)$$

where b_h is the average of R draws from the distribution of the estimated coefficient for attribute h, and b_C is the cost attribute coefficient. The draws were taken using the mean marginal WTP and its standard deviation.

4 Empirical results

4.1 Estimated Benefits

To expand their production aquaculture companies need a license. Hence, the relevant interpretation of the producer surplus is the net present value (NPV) of a license. When acquired, there is no restrictions on the period the license is valid for. However, under the traffic light system, if aquaculture is deemed environmentally unsustainable in a production area, the authorities may reduce the production capacity there. On this background we assume 10 years of operation for a license. Table A2 in the appendix presents average profit per license for companies in Troms and Finnmark counties for the period 2008-2017. This shows a huge range for the profit, from slightly negative in 2008, to a peak of almost 3.5 mill USD in 2016. The upper section of table 4 shows NPV per license depending on which year the license is bought and set into operation. The NPV is based on a license price of 11.765 mill USD, and annual profit equal to 2.464 mill USD. That license price is similar to the fixed price paid in 2017, and the annual profit is equal to the average annual profit for companies in Troms and Finnmark counties in 2015-2017. Licenses are assumed acquired every other year in line with the plans under the traffic light system for awarding new licenses and increased production capacity.

Table 4 about here

Net present value (NPV) of benefits and costs of aquaculture expansion, 2019-2028

The middle section of table 4 shows the NPV of transfers to the municipalities from the Aquaculture Fund, under a low, medium and high scenario. The municipalities will share 60% of license fees paid, based on their relative share of existing locality capacity. The total fees paid for new aquaculture licenses will depend on the national growth rate in license volume and the average fee paid per license. Payments into the fund and the main transfers to the municipalities will take place every second year, and the first payment from the fund was in 2018.[4] Given the growth in production capacity in the Tromsø-region in 2018, the region received 477,617 USD from the fund. The various payment paths are in table A1 in the appendix, and there the low, medium and high transfer payment paths are marked in bold.

4.2 *Costs*

We use results from the survey presented in section 3 to estimate costs associated with expanding aquaculture production. The survey was distributed electronically to 3000 of a total of 450,000 inhabitants in Arctic Norway. We obtained 1016 responses, of which we apply a sub-sample of 519 respondents.[5] Extracting respondents from Troms county, the Tromsø-region and Tromsø municipality, table 5 yields the marginal willingness-to-pay (WTP) for each of the attributes. While people were unambiguously willing to pay for less waste on

[4] The municipalities with new localities that have been cleared during the period being paid for share the last 10% of the license fees - in addition to their share of the previously mentioned 60% of the license fees. This takes place in the "other year". We leave out the payments for these newly cleared localities, as it is uncertain when they will be cleared. This omission does imply a somewhat lower estimated transfer from the Aquaculture Fund than would actually be realised.
[5] This was a split sample survey, where half of the sample got a version of the survey including the job attribute and the other half a version that only included environmental attributes.

the beaches, the other factors were more ambiguous, and mostly not statistically significant. One of the few significant estimates was “the presence of aquaculture”, which was significantly negative at 10% level for respondents in Tromsø municipality and at 15% level for respondents in the Tromsø-region. The WTP-estimate equal to -65.6 USD means that on average households in the Tromsø-region are willing to pay this amount to avoid more aquaculture activities in this region.

Table 5 about here

Estimated WTP for environmental and economic attributes characterizing the regional coastal zone, USD

The 12 new localities for aquaculture activities suggested in the coastal plan are distributed across the Tromsø-region. If aquaculture production takes place on all these new localities, fish farms will be visible in large parts of the region. Although significant only at 15% level, we choose to use the estimated WTP to avoid more aquaculture for households in the Tromsø-region as a proxy for costs of aquaculture expansion. The amounts in table 5 are average numbers. The large confidence interval for the variable “The presence of aquaculture” indicates that this WTP is unevenly distributed across the population, and to take into account this heterogeneity we use both the upper and lower 85% confidence intervals, in addition to the average WTP, as scenarios of the costs of aquaculture expansion. Table A3 in the appendix yields the various estimates of WTP applied, and the lower section of table 4 yields the NPV over the period 2019-2028.

4.3 Net benefits of aquaculture expansion in the Tromsø-region

Total net present value (TNPV) is the sum of NPV for acquiring and operating an aquaculture license in the region over 10 years (producer surplus) and NPV of transfers to the region from the Aquaculture fund over 10 years (rent), subtracted the NPV of willingness to pay for households in the region to avoid more aquaculture activities. We use 5% discount rate in the calculation of the NPV. The estimated NPVs are given in table 6.

Table 6 about here

Net present value of aquaculture expansion in the Tromsø-region during the period 2019-2028, for different scenarios for regional ownership growth, transfers from the Aquaculture Fund and WTP to avoid aquaculture, mill USD

The results in table 6 show that if there is no regional ownership growth, implying that no producer surplus remains in the region, the regional TNPV of such expansion is mainly negative. The regional TNPV is positive only if the WTP to avoid more aquaculture activities is low, and the transfers from the Fund is of the middle or high alternatives. If the producer surplus from operating three new licenses benefits the regional economy (medium regional ownership growth), the regional TNPV is positive unless the population's WTP to avoid more aquaculture is high. Finally, if the producer surplus from six extra licenses benefits the regional economy (high regional ownership growth) the regional TNPV is always positive. Hence, to ensure positive regional TNPV of aquaculture expansion some of the producer surplus generated from operating new licenses should remain in the region.

4.5 Non-quantified costs and benefits

There are possible benefits of aquaculture on municipal level that we have not been able to monetize. Conservation of social structure and improved infrastructure in rural areas (Neiland et al., 1991) are examples of such benefits. While the former is tightly linked to rural job opportunities, which will be discussed in the next section, the latter demands separate CBAs and is thus beyond the scope of this paper. One benefit that is relevant in a Norwegian context is the financial, technical and equipment sponsoring aquaculture companies offer to sports and cultural organizations and events in the local communities they operate. Especially in smaller rural municipalities, with few alternative sponsors, aquaculture companies may be important contributors. Still, compared to the amounts generated by transfers from the Fund and producer surplus, these benefits are small, and they can vary considerably over years. Hence, although possible, we have not monetized such benefits.

The most relevant cost-component mentioned by Neiland et al. (1991) for a CBA-analysis of aquaculture, and which we have not been able to monetize, is environmental damages. Aquaculture activities in Norway are closely monitored, and from 2011 the results have been reported and analyzed annually as part of an environmental risk assessment of aquaculture. According to the latest of these reports (Grefsrud et al., 2018), the two largest risks are salmon lice and escapees, both of which poses a threat to wild salmon stocks. The 2017 Aquaculture Risk Report (Svåsand et al., 2017) shows that the prevalence of sea-lice in Troms county is, together with Finnmark county, the lowest in Norway. Still, average number of female lice per fish has increased from about 0.1 in 2015 to about 0.15 in 2017. Further establishment of fish farms may lead to further deterioration, which in turn may have negative effects on local income generation based on tourism fishing in this river, reduced benefits for local recreational anglers, and also incur losses in salmon farming. Norwegian salmon rivers attract about 100,000 foreign and domestic salmon anglers annually, generating economic values equal to 162 million USD (Norske Lakseelver). Such numbers may be applied as input to the monetization of environmental damages of aquaculture production. The challenges is, however, to distinguish between impacts from aquaculture activity and from other factors influencing the state of the wild salmon, and in turn to estimate the loss of income experienced in the Tromsø-region.

Nikitina (2018) analyzed statistically the relationship between aquaculture production and the number of wild salmon returning to nearby rivers to spawn. She applied time-series data for 2005-2015 from all Norwegian salmon rivers and accompanying aquaculture facilities. The analysis, which included distance from aquaculture facilities to the salmon-river mouths, could not establish a statistically significant relationship between fish farm biomass and number of migrating wild salmon, but it indicated a weak negative impact of aquaculture biomass. Liu et al. (2014) and Olaussen et al. (2015) both estimate welfare and economic losses for wild salmon fishing in a “typical” Norwegian salmon river due to salmon lice from aquaculture, and while the former find insignificant impacts due to substitution effects, the latter find that such losses may range from 15 to 25%. Abolofia et al. (2017) estimate the national losses in Norwegian salmon farming due to salmon lice on farms. A challenge for utilizing these results in our study is that national average data is not easily transferable to the Tromsø-region, since sea lice levels are lower than the national average, and the economic impacts are not proportional to the sea lice levels.

Another cost mentioned in Neiland et al. (1991) is the loss of traditional occupations. In the hearings for the inter-municipal coastal plan for the Tromsø-region, representatives for industries like traditional cod fishing, shrimp fishing, and tourism, claimed that the establishment of aquaculture plants in their vicinity would reduce their possibilities for continued activity at present level, not to mention to expand this activity (Tromsø municipality, 2015). However, the literature on long-term effects of aquaculture on other marine industries is scarce, and the few reports that exist are inconclusive concerning negative effects on other marine species (Uglem et al., 2014; Uglem et al., 2017). In addition, such effects are difficult to verify as we usually do not know how these industries would have developed without aquaculture expansion.

5 Discussion and conclusions

It is municipalities that designate coastal areas to aquaculture activities, and their motivation depends on net benefits at municipal level from such use. Yet, there is little empirical evidence on costs and benefits of using coastal areas to aquaculture activities. Above we have monetized costs and benefits of aquaculture expansions for a region encompassing 5 municipalities in Arctic Norway, and estimated total net present value (TNPV) over a 10-year period. We show that a positive regional TNPV crucially depends on producer surplus from aquaculture remaining in the region. If this is not the case, transfers from the Aquaculture Fund in most cases are not sufficient to outweigh regional households' welfare loss from more aquaculture activities. The exception is the case when WTP to avoid more aquaculture activities is very low.

Uncertainties exist in the estimation of the producer surplus and payments from the Aquaculture Fund. These depend on salmon prices and production costs, growth in the number of new licenses nationally and fees paid per license. Salmon prices are expected to be relatively high for the next years, although smaller reductions are expected from the record-high level of 2017 (Dagens Næringsliv, 2018, Sjømat Norge, 2019). The costs of farming salmon have increased significantly and steadily the latter years, in particular for feed and the handling of sea-lice (Iversen et al. 2017). This indicates that future producer surplus may be lower than in recent years. Our results are, however, not very sensitive to changes in annual producer surplus.

On average, inhabitants in the region are negative to seeing (more) aquaculture. This result is, however, driven by a significant resistance in the urban municipality Tromsø, while inhabitants in the other municipalities of the region probably[6] does not have a significant willingness to pay (WTP) to avoid seeing (more) aquaculture activities. The rather large confidence interval for the estimated WTP indicates that even among households in Tromsø municipality the preferences regarding aquaculture activities are ambiguous, and we take this into account by using upper and lower 85% confidence interval limits[7] to test the robustness of the results with respect to variations in estimated WTP. This shows that assuming a high WTP (upper confidence interval endpoint) for avoid seeing aquaculture activities renders regional TNPV negative for both low and medium local ownership of new licenses (see table 6). Assuming a low WTP (lower confidence interval endpoint) renders a positive NPV even with no generated local producer surplus, but then demands medium or

[6] There are too few respondents from the other municipalities to generate unbiased results by the MNL-model for the region excluded Tromsø municipality.
[7] As we apply a WTP estimate that is significant only at 15% level, we also apply a 85% confidence interval for this WTP. Using e.g. a 95% CI would yield positive lower CI endpoint, and thus a trivial analysis for this case. We still would be able to use average and the upper CI endpoint as proxies for costs of aquaculture expansion.

high Fund transfers. This ambiguity regarding how inhabitants' WTP to avoid specified changes in the natural environment affects NPV of aquaculture expansions indicates the importance of mapping the values inhabitants hold for the natural environment.

The difference between the NPV of the benefits in terms of producer surplus and Fund transfer, and the costs, in terms of inhabitants' WTP to avoid aquaculture expansion yields the leeway to compensate for costs not accounted for in the regional TNPV. Thus, a positive regional TNPV indicates that some environmental damages from aquaculture expansion is possible without compromising overall regional benefits. The lack of knowledge on the extent of environmental damages from aquaculture, and on monetization of such effects, renders it impossible to conclude on this matter. On the other hand, it may be that the estimated WTP for households to avoid more aquaculture activities includes environmental damages. If so, it would be double-counting to add further environmental costs to the cost side. If the estimated WTP includes environmental damage costs, a relevant question is how the general public's assessment of environmental damages from aquaculture activities are compared to "expert" assessment of the same? Are there environmental damages that the public do not consider, or systematically over- or undervalue? These are questions for future research.

A premise for the above CBA has been that the suggested aquaculture expansion in the region is marginal to the regional economy, and thus doesn't affect prices or economic growth. Low unemployment in the region, including the rural municipalities, suggests that labor has alternative uses. Hence, we have not included producer surplus in related industries and labor remuneration. However, both population and employment have long been decreasing in some rural municipalities of the region. According to Burgan and Mules (2001), when there are few alternative jobs it may be appropriate to use value added to estimate regional benefits, which includes wage income as well as producer surplus. This would increase the regional TNPV of each scenario. It is also uncertain to what degree aquaculture expansion will crowd out revenues and jobs in other industries in Tromsø municipality, and to what degree it will contribute to economic growth. Robertsen et al. (2012) found that more than 50% of purchases from aquaculture companies operating in the region are made from regional suppliers. Economic ties between aquaculture producers and the supply industry may cause ripple effects, which in turn should be included in the regional TNPV. This would increase the NPV of all scenarios. The reason why we have not included such effects in our CBA is that these effects are uncertain. Table 7 summarizes how we have treated various factors of benefit and costs and how they alternatively could have been treated.

Table 7 about here

Components included in and excluded from the cost-benefit analysis of aquaculture expansions in the Tromsø region

Information from tables 6 and 7 may help answer the initial question on municipalities' motivation for assigning coastal areas to aquaculture. Our example shows that for a region with limited local ownership of aquaculture companies operating in the region, the net benefit of aquaculture expansion is likely negative. Still, many coastal municipalities in Norway prioritize aquaculture. How can this be? The fact that rural parts of the region have had decreasing population and employment, but still have low unemployment, indicates that for some people the alternative to work in an expanding aquaculture industry is to emigrate from the region. If aquaculture expansion implies growth in employment and population, this may help explain the municipalities' willingness to assign areas to aquaculture. However, even if turnover in both aquaculture and its supply industries in the region is growing, it is not clear how aggregate regional profits would grow. This depends on whether companies in these industries have capacity to grow without major investments. Furthermore, supply industry companies from outside the region may be attracted to the region, increasing competition and possibly lowering the profit rate in this industry.

Taking a long-term perspective may change the analysis dramatically. The salmon aquaculture industry in Norway is developing and testing several production concepts. These may affect future labor demand and the relevance of municipal coastal zone management to a large degree. This includes concepts for large scale offshore production, which will be located beyond municipal area jurisdiction (which is one nautical mile from the "baseline" connecting the outer headlands and outer side of islands less than 1 nautical mile from the shore). With such a development, fish farming would resemble oil and gas production, being capital intensive and with relatively less use of labor. This may favor large national and international companies and make it less likely that locally owned companies will acquire new licenses. Although uncertain, it will probably take many years, if not decades, before this becomes a major way of aquaculture production. Until then, municipalities will most likely remain central for handling and living with aquaculture expansion and its costs and benefits.

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Appendix

Figure A1 Example of choice card

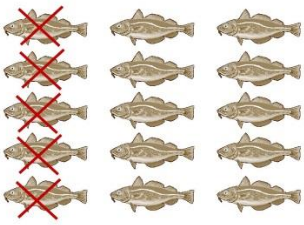
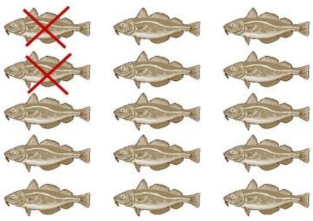
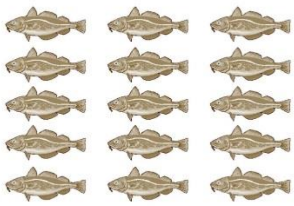
Attributes	Status quo	Regulation A	Regulation B
Waste	50% INCREASE 	25% INCREASE 	NO CHANGE 
Scenic view	AQUACULTURE AND MARINE FISHING TOURISM INCREASE 	AQUACULTURE INCREASE 	AQUACULTURE AND MARINE FISHING TOURISM INCREASE 
Quantity of recreational catch per boat per day	5 KG LESS PER BOAT PER DAY 	2 KG LESS PER BOAT PER DAY 	NO CHANGE 
Number of jobs created in Finnmark, Nordland and Troms	500	350	100
Increase in tax per household per year	0	2000 NOK	1000 NOK
Which one do you prefer?	☐	☐	☐

Table A1 Estimated transfers in 1000 USD from the aquaculture fund to the Tromsø region, based on growth-path for the period 2019-2028 given in Table 2, and depending on average license fees and annual national growth rate for aquaculture production capacity*

License fee, mill USD	**11.70**	**19.50**	**23**
Growth rate: 0.5%			
2020	**225**	375	444
2022	**339**	562	665
2024	**452**	750	887
2026	**564**	937	1109
2028	**677**	1124	1331
Growth rate: 1.0%			
2020	447	**742**	879
2022	671	**1 113**	1318
2024	894	**1 484**	1757
2026	1118	**1 856**	2197
2028	1341	**2 227**	2636
Growth rate: 1.5%			
2020	664	1103	**1 305**
2022	996	1654	**1 958**
2024	1328	2205	**2 610**
2026	1660	2756	**3 263**
2028	1993	3308	**3 915**

*payments from the Fund is done every second year, and was last made in 2018.

Table A2 Profit per license for aquaculture companies in Troms and Finnmark counties, 2008-2017

Year	Profit per kg, USD	Produced kg per license	Profit per license, 1000 USD
2008	-0,03	1,025,000	-31
2009	0,39	1,095,000	427
2010	0,785	1,130,000	887
2011	0,28	1,088,000	305
2012	0,145	1,498,000	217
2013	1,01	1,358,000	1,372
2014	0,80	1,543,000	1,234
2015	0,606	1,590,000	963
2016	2,28	1,507,000	3,440
2017	1,807	1,654,000	2,989
Period average	0,808	1,348,800	1,180

Sources: Directorate of Fisheries, Aquaculture statistics

Table A3 Total annual willingness to pay (WTP) to avoid aquaculture expansion in the Tromsø-region, 1000 USD

Municipality	**No of households**	**Total WTP in each municipality**	**Total WTP in each municipality (Lower WTP CI* limit)**	**Total WTP in each municipality (Upper WTP CI* limit)**
Tromsø	35 334	2,318	187	4,449
Målselv	3 001	197	16	378
Balsfjord	2 544	167	13	320
Lyngen	1 394	91	7	176
Karlsøy	1 046	69	6	132
SUM	**43 319**	**2,842**	**229**	**5,455**

*) Confidence interval

Figure 1 Map of the Tromsø-region including existing aquaculture localities.

Table 1 Identification of social and economic benefits and costs of aquaculture at national level

Benefits	Costs
Increase in fish supply	Environmental damage
Reduction in fish price	Conflict over resource usage
Export earnings	Creation of a resource sink
Creation of employment	Disruption of social structure
Conservation of social structure	Overfishing and reduced fish supplies
Improved infrastructure in rural area	Loss of traditional occupations

Source: Neiland et al. (1991)

Table 2 Growth path for aquaculture production in the Tromsø-region, 2019-2028

Year	**2020**	**2022**	**2024**	**2026**	**2028**
Additional capacity in tons	2362	3543	4724	5905	7086-
Cumulative number of new standard licenses	2.67	4.00	5.34	6.67	8.00-
Low scenario: no new licenses acquired by local owners	0	0	0	0	0
Medium scenario: three new licenses acquired by local owners	0	1	1	1	0
High scenario: six new licenses acquired by local owners	1	1	2	2	0

Table 4 Net present value (NPV) of benefits and costs of aquaculture expansion, 2019-2028

Benefit / Cost Year / Scenario	**NPV 1000 USD**
NPV of license depending on year of acquisition	
2020*	19,500
2022	15,961
2024	12,750
2026	9,838
NPV of transfers from aquaculture Fund	
Low transfers	4,111
Medium transfer	13,522
High transfer	23,773
NPV of inhabitants' WTP to avoid aquaculture expansion	
Average WTP	47,385
Lower WTP CI** limit	6,769
Upper WTP CI** limit	88,119

**) note that new aquaculture licenses are only issued every second year, and the last time they were issued was in 2018*

***) CI = Confidence interval*

Table 5 Estimated WTP in households, in USD, for environmental and economic attributes characterizing the regional coastal zone

Attribute	Troms county		Tromsø-region		Tromsø municipality	
	WTP	85% CI	WTP	85% CI	WTP	85% CI
The presence of aquaculture	-22.25	(-77.3, 32.8)	-65.6• (41.6)	(-125.9, 5.3)	-90.1*	(-167.6, -12.9,)
The presence of marine fishing tourism	26.63	(-82.38 29.1)	-1.13	(-71.3, 73.5)	5.63	(-90, 80)
More new jobs (per 100 job)	12.8	(-4.9, 3.0)	10.9	(-12.3, 34)	-4.5	(-30.5, 21.5)
Less waste on the beaches	753.1***	(396.4, 1109.9)	880.9***	(452.9, 1308.9)	1044***	(539.5, 1548.8)
Higher recreational harvests	14.9	(-3.6, 33.4)	9.3	(-11.4, 29.9)	5.8	(-13.4, 24.9)
LL-value	-1398.37		-928.64		-802.64	
Adj.R^2	0.21		0.2		0.2	
No of obs/ households	1626/205		1093/139		953/121	

*** = significant at 1% level, *=significant at 10% level, • significant at 15% level

Table 6 *Net present value of aquaculture expansion in the Tromsø-region during the period 2019-2028, for different scenarios for regional ownership growth, transfers from the Aquaculture Fund and WTP to avoid aquaculture, mill USD*

	Average WTP	**Lower WTP CI limit**	**Upper WTP CI limit**
Low regional ownership growth			
*Low fund transfer	-17.5	-0.15	-35.2
*Mid fund transfer	-13.7	4.0	-31.3
*High fund transfer	-9.0	8.7	-26.7
Medium regional ownership growth			
*Low fund transfer	5.4	19.5	-15.9
*Mid fund transfer	9.3	23.4	-12.0
*High fund transfer	13.9	28.1	-7.3
High regional ownership growth			
*Low fund transfer	31.5	39.6	4.2
*Mid fund transfer	35.4	43.5	8.1
*High fund transfer	40.1	48.2	12.8

Table 7 Components included and excluded in the cost-benefit analysis of aquaculture expansions in the Tromsø region

Component	**Treatment**
Producer surplus in aquaculture	Included for companies with local ownership.
Wages earnt in the aquaculture industry	Not included. Assumed equal to wages in alternative jobs. Low unemployment in the region suggests there are no net benefits of jobs in aquaculture. High unemployment could justify using value added, including wages, instead of only producer surplus as a measure of benefits to the region. Decreasing employment and population in some rural parts of the municipalities suggest there may be net benefits there of jobs in aquaculture.
Transfers from aquaculture fund to the region	Included. Depends crucially on the national growth in aquaculture licenses and their price
Producer surplus in related industries	Not included. This belong to economic impact analysis, assuming unutilized economic resource that are integrated into the economy and which would otherwise be vacant.
Population's willingness to pay (WTP) to avoid aquaculture expansions	Included. A survey shows that there is a significant WTP among the population in Tromsø municipality to avoid aquaculture expansions, but not in the other municipalities.
Social infrastructure	Not included.
Externalities	Not included explicitly, but may be partly covered by the population's WTP to avoid aquaculture expansions.