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Climate change and the value of fishing in the Arctic

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Abstract: Several studies indicate impacts on fish from climate change in the Arctic, but there is no study calculating the effect on the value of fishing. The value of fishing is determined not only by climate change, but also by other variables including prosperity and population density. The present study estimates the impact of these factors on the recreational value of fishing by using meta-regression analysis of studies estimating willingness-to-pay for fishing in the Arctic. The study includes 22 studies with a total of 107 observations, and the results indicate robust results with a positive relation between estimated value and temperature and prosperity, but a negative with precipitation. Using the results from the regression, simulations showed that increases by the same percent in temperature and precipitation give a minor net decrease in the fishing value, but an increase in the temperature with 1 ℃ can raise the average fishing value by approximately 15 percent.

Keywords: fish value, meta-regression, willingness to pay, climate factors, prosperity, Arctic,

JEL codes: Q21, Q51, Q57

1. Introduction

Arctic aquatic systems are affected by several environmental and anthropogenic factors including climate change and exploitation of natural resources (e.g. EC, 2020). The temperature increase is twice as high as the global average (e.g. CAFF, 2013). Climate change as a cause of global warming has been documented by a large number of studies (e.g. Box et al., 2019). This generates effects on e.g. the food web and nutrient status in lakes and seas, which will have impacts on the size and composition of fish species in the Arctic aquatic ecosystems (e.g. Reist et al., 2006; Campana et al., 2020). The direction of change might differ for different species, where, for example, the carrying capacity of Atlantic cod is expected to increase but that on salmon to decrease (e.g. Eide, 2017; Troell et al., 2017). Irrespective of the direction, the impacts will affect human welfare and the economies in the region. However, unlike studies in ecology on effects of climate change on fish species in the Arctic, studies on economic effects are in principle non-existing (Crepin, 2017; EC, 2020).

The main purpose of this study is to estimate the effect of climate conditions on the value of fishing in the Arctic. Climate change can affect the value in two ways; directly through alterations in the perceived value and cost of fishing, and indirectly through the impact on fish populations. Starting in the early 1970s, there is a large body of studies estimating the willingness-to-pay for fishing (e.g. Johnston et al., 2006; RUVD, 2016), but none of the studies consider climate effects. On the other hand, there is a large body of literature in ecology of climate effects on fish population size and composition (e.g. Eide, 2017; O'Gorman et al., 2018; Campana et al. 2020).

There are a few studies estimating the value of climate impacts on other ecosystem services than fishing, such as effects on savannah ecosystem services and carbon sequestration in forests (e.g. Scheiter et al., 2019; Gren and Amuakwa-Mensah, 2020). These studies use bio-economic modelling of the interaction between human decision making and ecosystem dynamics and examine how the optimal value of the ecosystem services are affected by climate conditions. Other studies use a more simple framework (although sophisticated climate-ecosystem model) without consideration of responses by humans, by assigning constant unit values of changes in the supply of ecosystem services (e.g. Schaw et al., 2011).

This study suggests an alternative approach; meta regression analysis (MRA) with inclusion of climate variables. MRA was first suggested by Glass (1976) and it is a tool for a systematic extraction, quantification and synthesis of results from existing studies. Methods have been developed to account for differences in study characteristics (e.g. Nelson and Kennedy, 2009), with an application to the value of fish (Johnston et al., 2006). MRA is often used to transfer benefit estimates of ecosystem services from one situation to other similar situations. In this study, we are interested in extrapolating impacts of climate change from limited locations in the Arctic. By combining information on estimated values and study characteristics with climate variables at the source region of the study it is possible to estimate the effect of the climate variables on the fishing value. A similar approach was used by Gren and Tafesse (2020), who used MRA to estimate costs of mussel farming, where salinity and water temperature entered the regression equation together with data on costs, site-specific conditions, and study characteristics.

In the authors' view, the novel contribution of this study is the use of a new method, MRA, for estimating effects of climate change on the value of an ecosystem service, with an application to fishing value in the Arctic region. The study also extends the literature of MRA of the value of fishing, which has been made by only one study (Johnston et al., 2006) who focused on one value measurement, value of a fish, and included only studies applied to Canada and USA. The present study is organized as follows. Section 2 describes the conceptual approach in the determination of impacts of climate on the value of fishing, and data retrieval is presented in Section 3. Econometric specification and results are presented in Section 4, and effects of climate change are calculated in Section 5, the results are discussed and conclusions are drawn in Section 6.

2. Conceptual approach

The point of departure in the present study is that climate change can affect the value of fishing in two ways. One is through the impact on the utility of fishing as such, which can be affected by logistical difficulties of reaching the stream due to e.g. heavy precipitation. The second mechanism is through the impact on fish populations. Several studies have shown that the population of fish species in the Arctic waters can be affected (Eide et al., 2017; Troell et al., 2017; Campana et al., 2020). If the number of fish catches affects the utility, a larger catch for a given effort is likely to have a positive impact on utility, and vice versa. These two linkages between climate change and the net value of fishing are illustrated in Figure 1.

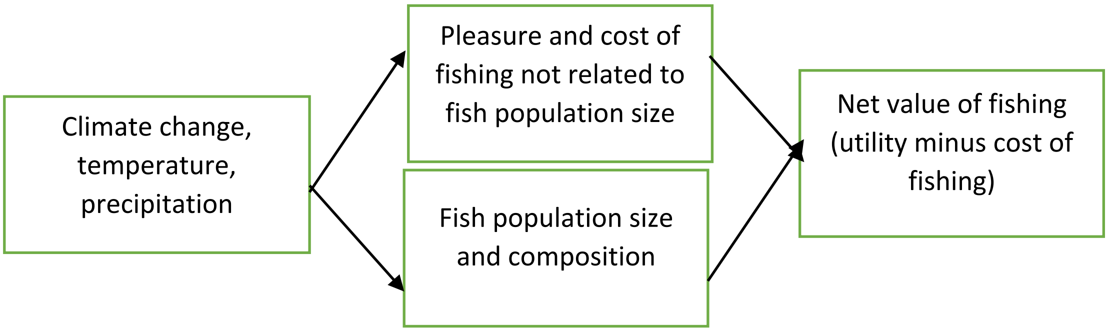


Figure 1: Illustration of impacts of climate factors on the value of fishing

In order to disentangle the impacts through these two channels, a simple model of the determinants of fishing value is constructed. The value for an angler, V^i, where $i=1,\ldots n$ is anglers, then measured as the net value of the utility of fishing minus the cost. The utility for an individual i, U^i, is determined by harvest, H^i, and other factors such as pleasure from nature experiences and social life with other recreationalists, O^i. In general, it is regarded that wealth and prosperity, I^i, affects the utility (e.g. Johnston et al., 2006). The impact of the climate, Y, on the fish population and thereby H^i is likely to be determined by effects on ecological conditions in the waters, E, such as nutrient concentration and water temperature. The cost of fishing includes expenses for equipment, travel, and opportunity cost of the time spent on fishing, C^i, which is determined by climate change and e.g. prices equipment and travel, denoted by p. The net value of fishing for an individual, V^i, is then determined as:

$$V^i = U^i(H^i(Y,E), O^i, I^i) - C^i(Y,p) \qquad (1)$$

Effects of a marginal change in climate Y on V^i is obtained by differentiating eq, (1) with respect to Y, which gives:

$$\frac{\partial V^i}{\partial Y} = \sum_k \frac{\partial U^i}{\partial H^i}\frac{\partial H^i}{\partial Y^k} - \frac{\partial C^i}{\partial Y^k} \qquad (2)$$

where $k=1,..,m$ different climate variables such as temperature and precipitation. Whether $\frac{\partial V^i}{\partial Y} \leq (\geq) 0$ depends on the direction of impact on each of the climate variables, k, and the effects on utility and costs of fishing. It is assumed that $\frac{\partial U^i}{\partial H^i} \geq 0$ and the effect on utility is then determined by $\frac{\partial H^i}{\partial Y^k}$, if it is positive the impact is positive and vice versa. Similarly, the effect on cost of fishing depends on the sign of $\frac{\partial C^i}{\partial Y}$. The only robust conclusion regarding effects of climate change on the value of fish is then that it is positive only if $\frac{\partial U^i}{\partial H^i}\frac{\partial H^i}{\partial Y^k} > \frac{\partial C^i}{\partial Y^k}$, and negative otherwise.

Although simple, the analysis shows the existence of two mechanisms of impacts of climate change on the value of fishing, and that the net effect of these cannot be determined theoretically. Further, it points out the needs of data to examine whether climate change has a positive or negative net impact on V^i and measure the direct and indirect effects in eq. (2). There is a need to disentangle the effect of climate change in relation to the effects on V^i from the other variables included in eq. (1). In addition to the dependent variable V^i, data is needed on the independent variables H^i, C^i, O^i, I^i, p, E, and Y. In addition, we would also expect the V^i to differ for different fish species and type of fishing activity.

3. Description of data

Data on V^i is obtained by a systematic review of studies estimating value of fishing. In MRA, the collection of studies and choice of dependent and independent variables are essential. Ideally, there is data on all the independent variables listed in eq. (1). However, in addition to these variables, the estimated values in the studies are likely to differ depending on choice of valuation object, valuation measurement, and valuation method which is described in the following.

3.1 Collection of studies

Source study identification was obtained by three different methods; *i)* various combinations of the keywords *fishing OR fish AND Arctic AND value OR willingness to pay* in different data bases of studies, *ii)* collection of studies from existing databases on fish values, web pages of agencies and authors known to have undertaken non-market valuation of fishing, and *iii)* application of the snowball method. The Arctic region is defined as northern regions in USA, Canada, Sweden, Greenland, Iceland, Norway, Finland and Russia (Heleniak, 2020). The search was made during the period from winter 2020 to summer 2021.

Several databases were used including Google, Google Scholar, REPEC/Ideas, Research Gate, Scopus, Semantic Scholar, and Web of Science. The Web of Science and Scopus websites provided studies published in journals. The other databases contained data on studies in the 'grey literature', which include reports from non-academic institutions, and reports and working papers from academic institutions that are not published in journals. RUVD (2016) was an important data base which includes studies on fishing recreation values in USA and Canada during 1958 and 2015. The snowball method was particularly useful for identifying many studies from references within or to a specific study, in particular to Johnston et al. (2006) which is the only review studies of fishing values.

In addition to data on fishing value, there were three types of requirement for including a study in the analysis. In order to account for study specific characteristics there is a need for information on fish species subject to valuation, valuation method, and valuation measurement. In total, 22 studies were found with this information (see list of studies in Table B1 om Appendix B). These studies were applied to three countries within the Arctic region; USA (Alaska), Canada (Yukon, the Northwest territory, and Novanut), and Sweden (Västebotten and Norrbotten), The studies provided 107 usable observations, resulting in an average of 4.8 observations per study which is close to the average of 4.9 in environmental economics meta-regression studies reported by Nelson and Kennedy (2009). Almost all studies were applied to Alaska. Three studies estimated values in other countries; 1 study with 3 observations to Canada and 2 studies with a total of 7 observations to Sweden.

2.2 Dependent and independent variables

The estimated fishing value constitutes the dependent variable in this study, and it is measured in year 2018 USD. The conversion to year 2018 values was based on country-specific consumer price indices (World Bank, 2021), and converted into USD using the average exchange rate for 2018 (The Swedish Riksbank, 2021).

Data on climate variables is obtained from the latest (released in January 2020) publicly available database (WorldClim, 2020). The data base contains historical climate data for 1970-2000 and includes among others mean temperature (^{o}C) and precipitation (mm). For this paper, we used climate data with a spatial resolution of 10 minutes (~340 km^2). This spatial resolution was sufficient to capture the data needed for each study's waterbody location.

The geocoded GeoTiff information is matched to the geographic specific location or site of each study's waterbody based on its longitude and latitude. Latitude and longitude information for the various studies is based on a specific waterbody location, locality, state, regional or country level and has been collected mainly from latlong.net, lat-long.com, latitude.to, findlatitudeandlongitude.com, waterdata.usgs.gov, geodata.us, waterqualitydata.us, w3.org, topozone.com, geohack.toolforge.org, mapsofworld.com, climate-charts.com and elevation.maplogs.com among others (e.g., NOAA coastwatch). Geoprocessing of the two datasets using QGIS 3.14.1 software is then conducted to retrieve the relevant climate variables for each study.

Region or state income per capita is used as a measure of income, and population density as a proxy of environmental pressure on waters. For USA total state income is obtained from BEA (2020) and BEA (2004). Population data in each state is found in CDC (2021) and US Bureau of Census (2020). Similar data for Canada is found in Statistics Canada (2020) for population and in Statistics Canada (2021) for income. Data for Sweden is obtained from Swedish Statistics (2020) for population density and from Swedish Statistics (2021) for GRP/capita.

The study characteristics include the fish species valued in the study, the value measurement method, and the unit of value measurement. All these factors are treated as dummy variables. Regarding choice of fish species, relatively many studies estimated values of Salmonidae species such as trout and salmon. Several studies used more general definitions such as freshwater or cold-water species. In this study, dummy variable are introduced for two species categories; ‘Salmonidae’ and ‘Other fish’. The latter includes all other and non-defined fish species.

With respect to value elicitation method, the methods for obtaining estimates of non-market values of is usually divided into revealed and stated preference methods and previous MRA studies have shown that choice of method affect the results (e.g. Johnston et al., 2006). Revealed preference methods are based on behaviour in indirect markets, which can be related to changes in fishing conditions. The travel cost method (‘TCM’) is one of the most applied revealed preference methods and links unpriced public goods to a priced market good. Limitations of the revealed preference methods include measurement of only so-called use values, such as the recreational value of fishing, and the need for a link between the market and non-market good, which may not always apply, in particular for multi-purpose trips. Therefore, stated preference methods were developed which include contingent valuation methods and choice experiments (‘SPM’). These methods are based on surveys to elicit respondents willingness-to-pay or accept compensation for environmental changes. Regarding unit of value measurement, the studies applied different approaches where the value per day (‘Day’) is most common. Other measurements are value per trip (‘Trip’) and a mix of unspecified measurements, per fish and per person merged into one variable (‘Othermeasure’).

Similar to most studies on MRA, a dummy variable is introduced for studies published in scientific journals with independent referee system (‘Journal’) and other publication outlets (‘Nonjournal’) which can be reports at universities, public authorities and private firms (e.g. Rosenberger and Johnston, 2009; Vedogbeton and Johnston, 2020). A test is also made of publication bias, which is described in Section 4.

The model includes 11 explanatory variables, and associated descriptive statistics for all variables are displayed in Table 1.

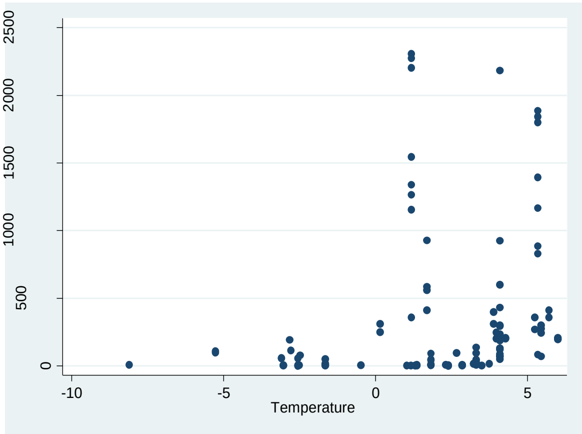
Table 1: Descriptive statistics, N=107

	Mean	St dev	Minimum	Maximum
Value, constant 2018 USD	352.04	567.50	0.68	2306.88
GRP/capita, 1000 constant 2018 USD	76.29	14.19	31.97	116.11
Year of study	2004	8.69	1987	2019
Population/km^2, thousand	0.66	0.97	0.07	5.40
Temperature, $^\circ$C	2.15	2.87	-8.11	5.99
Precipitation, mm	95.30	70.11	18.33	312.58
Region:				
USA	0.91		0	1
Other countries	0.09		0	1
Fish:				
Salmonidae	0.42		0	1
Other fish	0.58		0	1
Publication:				
Journal	0.58		0	1
Non-journal	0.42		0	1
Valuation method:				
RPM	0.51		0	1
SPM	0.49		0	1
Value measurement:				
Day	0.51		0	1
Trip	0.15		0	1
Other measure	0.34		0	1

The estimated average value of fish amounts to 352 USD, but the variation is large. One reason can be the value measurement, where value per day was the most common measurement unit. Another the choice of fish species, where salmon and trout account for 42 % of the total number of observations. It can also be noticed that most of the observations, 58 %, are obtained from studies published in scientific journals and that almost all studies are applied to fishing in Alaska.

4. Econometric specification and results

As a first guess on the relation between fishing value and climate change, simples plots are made between fishing value and the climate variables (Figure 2). The plot of the value and temperature indicates a positive relation while the plot of data on fish value and precipitation is less clear.



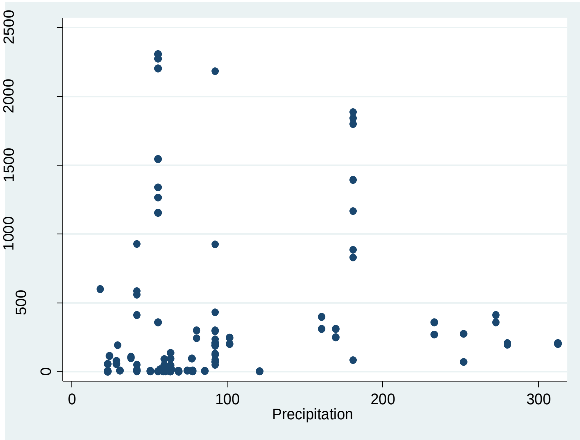


Figure 2a Figure 2b

Figure 2: Plot of data on fishing value and temperature (Figure 2a) and fishing value and precipitation (Figure 2b)

The plot in Figure 2a indicates a non-linear relation between temperature and the value of fishing with large increase at temperature exceeding 0 ˚C. However, these observations can also be explained by other factors, such as high-income levels, value measurements and methods. For example, the value of a trip is likely to be higher than a value per day since a trip usually lasts for several days.

The estimation of the impacts of different factors faces a main challenge typical for MRA studies. The dataset is hierarchical with studies at the top level and observations at the bottom level, which creates a risk of correlation within and between studies. Within-study correlation may occur from the use of a specific valuation method and data in a study, and between-study correlation from use of the same valuation method. Therefore, a mixed effect model is used, which accounts for the existence of correlation in observations within and between studies (e.g. Gelman and Hill, 2007). The method is much used in meta-regression analysis (e.g. Nelson and Kennedy, 2009; Hedges et al., 2010).

Study-specific effects may impact the intercept and the estimated coefficients of the independent variables. Tests were made using maximum likelihood estimator with random effects on only the intercept and with impacts on the intercept and on the slope of GRP/capita with assumption of independence in the covariation. The results showed best statistical fit when random effects are included in the intercept and the slope.

There are no prior expectations on the relation between the continuous variables and fishing value and we tested for different specifications of these variables. The results indicated best statistical fit, as measured with AIC and BIC, with the logarithm of fishing value, GRP/capita and population density and linear specification of temperature and precipitation. The following regression equation was then estimated:

$$\ln V_{i,j} = \alpha_0 + \alpha_1 \ln GRPC_{i,j} + \alpha_2 \ln POP_{ij} + \alpha_3 Temp_{i,j} + \alpha_4 Prec_{i,j} + \sum_h \alpha_{5,h} X_{i,h} + \lambda_{0.j} + \lambda_{1,j} + \varepsilon_{i,j} \quad (3)$$

where $V_{i,j}$ is the value of observation *i* in study *j*, $GRPC_{i.j}$ is the GRP/capita, *POP* is population density, *Temp* is temperature, *Prec* is precipitation, and $X_{i,h}$, is a vector of study characteristics where $h=1,\dots,m$ characteristics. The random effect at the study level in the intercept is presented by the term $\lambda_{0.j}$ and in the coefficient of ln$GRPC_{i,j}$ by the $\lambda_{1,j}$, and $\varepsilon_{i,j}$ is the stochastic error term at the individual level.

The regression equation was estimated with *Journal*, *Salmonidea*, *RPM*, and *Day* as the reference for the dummy variables. There are then 10 observations per predictor, which is regarded sufficient although larger number of observations are advised (Katz, 2006). However, most of the variables (6) denote study characteristics, and we therefore present regressions with and without these variables. Tests did not show any concern for multicollinearity, with an average VIF (Variance Inflation Factors) of 3.21 and none of the VIFs above 6.3 (e.g. O'Brien, 2007). A Breusch-Pagan test revealed problems with heteroscedasticity, and robust standard errors were therefore estimated. Results from the two regression models are presented in Table 2.

Table 2: Regression results of mixed effect models with *lnalue* as dependent variable and with and without study characteristic variables (N=107, Studies=22)

	Model 1: Coefficient	**s.e.**	**Model 2 : Coefficent**	**s.e.**
Constant	164.076***	53.305	-14.033**	6.637
Lngrpc	1.745*	0.968	1.640***	0.611
Lnpop	-0.235**	0.094	-0.355***	0.129
Temperature	0.152**	0.065	0.163***	0.056
Precipitation	-0.005*	0.002	-0.005*	0.003
Year	-0.090***	0.029		
Non-USA	0.035	0.329		
Non-journal	0.601	0.450		
Otherfish	0.715**	0.297		
SPM	0.158	0.435		
Trip	3.124***	0.486		
Other measure	0.801	0.575		
Random effect parameters				
$\lambda_{0\ i}$	0.000	0.000	0.000	0.000
$\lambda_{1\ i}$	0.008	0.004	0.012	0.024
$\varepsilon_{i\ i}$	0.543		0.661	0.349
Model statistics				
Prob>Chi^2	0.000		0.000	
AIC	304.503		318.239	
BIC	342.102		339.622	
McFadden's R^2	0.13		0.05	

Significance: ***p<0.01, **p<0.05, *p<0.10

Both models show statistically satisfactory results with statistically improved results compared with models without covariates. Each model also contains statistically significant independent variables. Results common to both models are the significant effects of *lngdpc*, *lnpop*, *temperature* and *precipitation*, which have the same coefficient signs in both models.

McFadden's R^2 is higher for Model 1, and this model is therefore used in the subsequent analyses. Before proceeding, a test is made of the existence of publication bias (e.g. Nelson and Kennedy, 2009). Test results using weighted least squares did not support existence of publication bias (Appendix A).

The estimated coefficient of *lngrpc* of 1.745 in Model 1 implies that the fishing value increases by 1.745 % when income increases by 1 %, which implies a relatively high income elasticity. Similarly, the coefficient of *lnpop* measures the elasticity with respect to changes in population density, where an increase by 1 % reduces the value by 0.235 %. This can be explained by eventual environmental impacts on fish populations in densely populated areas, but also on the eventual negative effect of congestion at fishing sites (e.g. Melstrom and Welniak, 2020). The two climate variables show opposite effects. An increase in the temperature by 1℃ increases the value with 0.152 of the fishing value, and an increase in precipitation by 1 mm reduces the value by 0.005 of the fishing value.

Regarding study characteristics, the results indicate significant effects of *Year*, *Other fish*, and *Trip*. The negative sign of *Year* shows a decline over time in the estimated value. The results also show that the value of *Other fish* is higher than of *Salmonidae*. The positive effects of *Trip* is expected since it in general lasts for a longer period than a day.

5. Effects of climate variables

The estimated regression Model 1 in Table 2 is used to simulate effects of change in the climate variables on the fishing value. To this end, simulations are made at the average values of all significant variables, and the constant is then calibrated accordingly. The value function is then written as:

$$\begin{aligned}\ln V &= 177.83 + 1.745 * \ln grpc - 0.235 * \ln pop + 0.152 * Temp - 0.005 * Prec \\ &\quad - 0.090 * Year + 0.715 * Otherfish + 3.124 * Trip\end{aligned} \tag{4}$$

The marginal effects of temperature, *Temp*, and precipitation, *Prec*, are determined as:

$$\frac{\partial V}{\partial Temp} = 0.152 * V \text{ and } \frac{\partial V}{\partial Prec} = -0.005 * V \tag{5}$$

In the reference case, *V* is determined at the mean value of fish (352 USD in Table 1) and at the means of all independent variables. Estimates are also made of marginal values for different fish species and measurement units.

Table 3: Calculated effects on the fishing value of marginal changes in temperature and precipitation for different fish species and measurement units, USD.

	Reference	**Salmonidae:**		**Other fish:**	
		per day	**per trip**	**per day**	**per trip**
Temperature	53.51	22.12	500	45.22	1024
Precipitation	-1.76	-0.73	-16.47	-1.49	-33.69

The results in Table 3 show large differences in the impacts on the fishing value of marginal changes in the climate variables depending on fish species and measurement units. For both climate variables, the highest impact is on *Other fish* when measured per trip, which can be 20 times higher or lower than the reference values for temperature and precipitation, respectively.

The marginal impacts in Table 3 are calculated at the means of all independent variables. It is also of interest to examine impacts on the fishing value at different levels of the two climate variables. This is made separately for each of the climate variables for the reference case at the mean values of all other independent variables. In addition, calculations are made for a 10 % increase in income and population density, which is motivated by the expected increases in these variables in the future in the Arctic region (Eide et al., 2017).

Calculations are made for changes in the temperature between 1 and 4.5 C˚, and the fishing value can be doubled within this range (Figure 3).

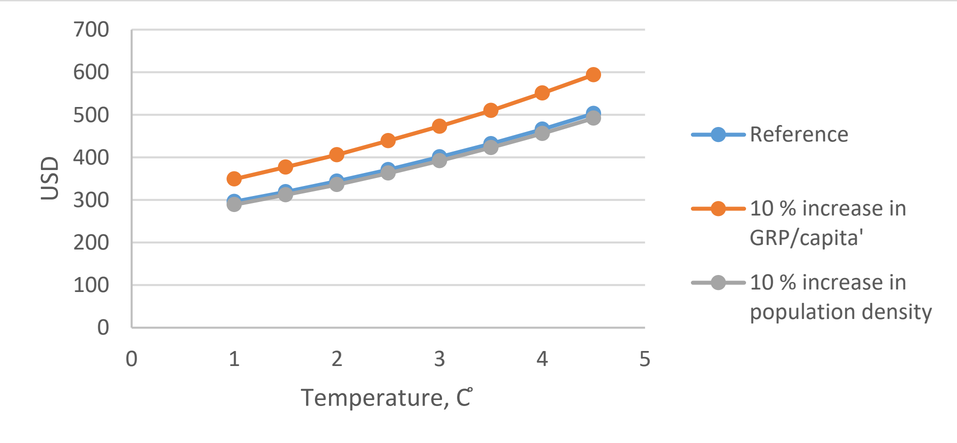


Figure 3: Calculated fishing value at different levels of temperature in the reference case and 10 % increase in income and population density

A 10 % increase in GRP/capita raises the fishing value at all levels by approximately 18%, but the corresponding increase in population density has a minor effect where the fishing value decreases by 2 % at all levels. It can also be noted that an increase in the temperature from the average of 2.15 ˚C would increase the fish value by 43% in the reference case. However, if also the income increases by 10%, the combined effect would be an increase in the fishing value by 68%.

Estimates of the fishing value for changes in precipitation are made at levels between 25 mm and 200 mm, which are within the range of the data set The fishing value then shows a considerable reduction from the lowest to the highest precipitation level (Figure 4).

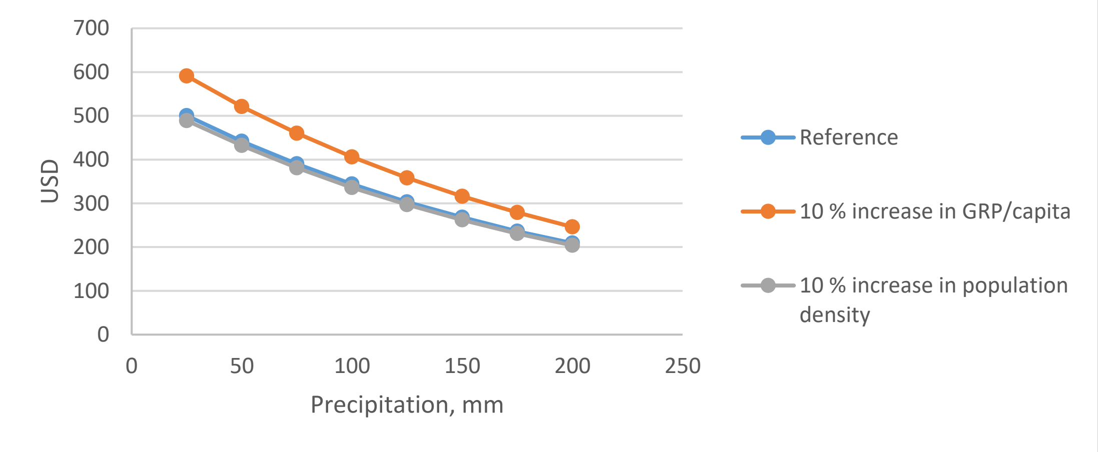


Figure 4: Calculated fishing value at different levels of precipitation in the reference case and 10 % increase in income and population density

Similar to effects of change in temperature, the fishing value is higher at all levels when GRP/capita increases by 10 % and slightly lower for a corresponding increase in population density. An increase from the mean of 95.3 mm to 200 mm would decrease the fish value by 43 %. This decrease would be mitigated by a simultaneous increase in income, and the net effect would then be a decrease by 30 %.

Given the two counteracting effects of the climate variables, it would be interesting to calculate effects of simultaneous increases in both. However, while climate change is manifested in increased temperature, the impact on precipitation is less clear. According to Box et al. (2019) it is most likely that the hydrological cycle changes and precipitation increases in the Arctic region. It could be drier or more wet. Calculations are therefore made for two cases; the same per cent increase in both temperature and precipitation and an increase in temperature and decrease in precipitation (Figure 5).

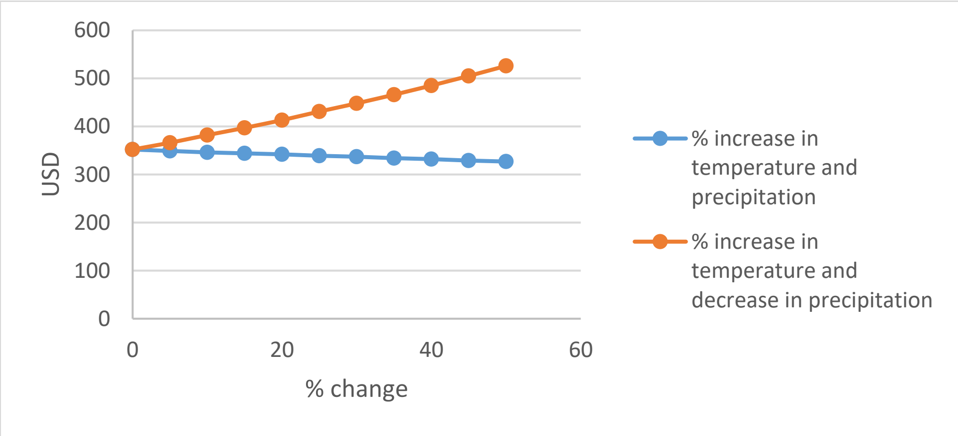


Figure 5: Fishing value at different simultaneous changes in temperature and precipitation from the reference values (temperature 2.15 C˚and precipitation 95.3 mm).

When both climate variable increase by the same per cent, there is a slight decrease in the fishing value. At the 50 % increase, the fish value decreases by 7 %. On the other hand, when precipitation decreases and temperature increases there is an increase in the fishing value, which corresponds to 49 % at the 50 % change level.

6. Discussion and conclusions

The main purpose of this study was to estimate the impact of climate related variables on the value of fishing. To this end, a conceptual model was constructed which showed two impact pathways of climate variables: directly on the angler's utility and indirectly through the effect on fish populations. It is well known in economics that the value of fishing is determined by a number of different factors in addition to climate factors, such as prosperity and costs of fishing. However, the only robust theoretical conclusion was that the impact of climate variables is positive only if the effects on both pathways are positive, which is an empirical issue.

Meta regression analysis was used to estimate the impact of climate variables (temperature and precipitation) on fishing value when considering the simultaneous effects of prosperity and accounting for study specific characteristics, In total, 22 studies on valuation of fishing in the Arctic region, with a total of 107 observations. Almost all studies were applied to Alaska and they accounted for 90 % of the observations. The average fishing value was 352 USD, but the variation was high between the studies. Using a mixed effect regression model, this variation was explained by the climate variables, prosperity, and study characteristics. The significant study characteristics included year of study, value measured for a fishing trip, and for non-Salmonidae species.

The estimated regression equation was used to calculate effects on fishing value of changes in the climate variables, marginal and total values. The value of an increase in temperature by 1℃ varied between 22 USD and 1024 USD depending on value measurement and fish species. Similarly, an increase in precipitation by 1 mm reduced the value by approximately 1 or 34 USD depending on measurement and fish species. Because of these counteracting effects on the value of fishing from the two climate variables, it was of interest to calculate the net effect from a simultaneous increase by the same percent in the two variables. The net effect was a slight increase in the average value, which amounted to 7 % decline from the reference value when the two climate variables increased by 50 %. On the other hand, if precipitation decreases and it becomes more dry, the combined effects instead raise the value by approximately 40 %.

It is not possible to compare the results with other studies since similar estimations have not been made. The effects of the two climate variables can be explained by impacts on preferences for fishing not related to fish populations and/or effects on fish populations. Partial comparisons are possible with studies estimating effects of income and study characteristics on fishing value and studies assessing effects of climate change on fish populations. Johnston et al. (2006) used MRA to estimate the value of marginal fish with a range between 0.05 and 613 USD (In 2003 value), with an average of 16 USD. This can be compared with an average of 352 USD in this study, which ranges between approximately 1 and 2307 for all valuation methods, species and measurements.

Similar to the present study, Johnston et al. (2006) found a significant and positive effect of income on the value. This is a common result for the value of any good; when income increases demand for a normal good increases. Unlike results in the present study, Johnston et al. (2006) obtained significant effects of valuation method and design. They also found significant effects of angler characteristics, such as age, which could not be made in the present study because of lack of data from all included studies.

An increase in fish population will, according to economic theory, raise the value of fishing because of large catches. There is large body of literature indicating that fish species move northwards with climate warming (e.g. Fossheim et al., 2015; Frainer et al., 2017), and that populations of established fish species in the Arctic, such as Atlantic cod and lake trout, increase (e.g. Eide et al., 2017; Campana et al., 2020). Campana et al. (2020) calculated an average increase in yield per recruit of lake trout by 8.4 % in Canadian Arctic lakes during the period 2006 to 2050 for which IPCC predicts an average increase in temperature in the Arctic region by 2.8 ˚ C. This will improve conditions for subsistence fishing for indigenous people who harvest lake trout (Islam and Berkes, 2016).

However, the effect of precipitation on fish populations is less clear. Patrick (2016) showed that the fish catch decreases as a result of increased dispersion of fish populations due to heavy rainfall. If so, the cost of catching fish may increase and net welfare decline. On the other hand, Campana et al. (2020) suggested that dispersal of fish eggs may increase as a result of precipitation and flooding and thereby expand the number of habitable lakes.

However, several relevant variables were excluded because of lack of data, such as anglers' characteristics and income. GRP per capita was used as a measure of prosperity, and this reflect anglers' income only if their income follows the same pattern over time and between lake regions. Lack of fish population data implied that it was not possible to disentangle the effects of climate variables on the direct and indirect effect on the value. The fish population could very well decrease or increase as a result of the climate impacts, which can be counteracted by the direct effects on welfare by e.g. reduction or an increase in costs of fishing. Nevertheless, the results seem reasonable based on the partial comparison with other relevant studies and pointed out potentially counteracting effects of temperature and precipitation on the fish value in the Arctic region.

Appendix A: Test of publication bias

In general, it is regarded that significant results are more likely to be published than non-significant results, and the existence of publication bias would include a variable of the standard error of each observation (e.g. Nelson and Kennedy 2009). Such data is not available for most of the studies included in the study, which is a common problem for MRA studies. As shown by Stanley and Rosenberger (2009) the square root of the inverse of the sample size, $1/\sqrt{S_{ij}}$ where S_{ij} is the sample size of observation *i* in study *j*, can be used as a satisfactory measure of precision in the estimates. Following Vedogbeton and Johnston (2020) we test for the existence of publication bias by introducing this proxy variable as an independent variable, and use weighted least square (WLS) with sample size as weight (Table A1).

Table A1: Regression results of weighted least square with sample size as weight (N=106)

Variable	Coefficient	Standard error
Constant	372.568***	28.94761
$1/\sqrt{S_{ij}}$	-1.217	5.974
Ln grp/capita	5.922***	0.710
Ln population density	0.378	0.359
Temperature	0.072**	0.028
Precipitation	-0.008***	0.002
Year	-0.217***	0.017
Non-journal	0.839**	0.362
Other fish	0.616	0.429
SPM	1.025**	0.365
Trip	4.489***	0.491
Other measure	1.297	0.850
Adjusted R^2	0.88	

Appendix B: Tables

Table B1: List of studies included in the MRA

No	Study	Observations
1	Aiken, R, 2006.	1
2	Aiken, R, and G,P, la Rouche. 2003.	1
3	Boyle, K.J. et al. 1998.	2
4	Brown, G, and M,J, Hay 1987.	1
5	Criddle Ket al. 2003.	2
6	Duffield et al. 2001.	14
7	Duffield et al. 2007. .	4
8	Harris (2006).	1
9	Hausman et al. (1995).	2
10	Henderson et al. (1999).	2
11	Jones and Stokes (1991).	16
12	Larson and Lew (2005).	1
13	Layman et al. (1996).	1
14	Federal-Provincial-Territorial Task Force on the Importance of Nature to Canadians (2000).	3
15	Carlen et al. (2021)	2
16	Bennear et al. (2005).	1
17	Berman et al. (1997).	1
18	Carson et al. (1990).	1
19	Carson et al. (2009).	25
20	Lew and Larson (2015).	15
21	Lew (2019).	5
22	Paulrud and Laitila (2004).	4

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