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# Reconstructed Russian Fisheries Catches in the Barents Sea: 1950-2014

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The management of marine living resources that straddle country borders has historically been a challenge, particularly in cases where political tensions are high. The jointly managed fisheries resources in the Barents Sea are a notable exception, wherein the Russian Federation (formerly Soviet Union) and Norway have relatively successfully managed fish stocks together since the 1950s, including during the high tensions of the Cold War and the dissolution of the Soviet Union. Using ICES statistics as reported baseline landings, the total catch of the region by the Russian fisheries was reconstructed for the period 1950-2014. Total catch was divided into reported landings, unreported landings, and discards, and assigned to four sectors: industrial, artisanal, recreational, and subsistence. Unreported landings and discards between 1950 and 2014 accounted for ∼12 and 55% of the total catch, respectively, with discards being substantial in the early decades. A majority of the catch was caught using pelagic and bottom trawls, contributing to the high rate of discards. Both discards and landings reached their peak in the 1970s, after which overexploitation contributed to numerous stock declines. Stocks recovered in the 1990s following adoption of legislation and gear regulations limiting discards as part of a joint effort by Norway and Russia to more sustainably manage stocks. The trend of declining Russian Barents Sea catches after the 1980s matches global trends of declining catch, although the present case appears to be mainly due to more successful management interventions. It is assumed that small-scale fisheries removals are minor in the region, but further research to refine estimates of small-scale fishing can improve upon the present study. While this study highlights historical declines in catch due to overexploitation, it does not explore fluctuations in catch caused by environmental variation. In the rapidly warming Arctic region it is of vital importance to understand how stocks may be further affected by climate change in addition to fishing pressure.

**Keywords: trawling, discards, cooperation, unreported catches, industrial fisheries, artisanal fisheries, subsistence fisheries**

## INTRODUCTION

Natural resources are often casualties in human disagreements and political struggles, and resources in the sea are no exception. International cooperation in fisheries is particularly important as fish are not a stationary resource that respect human-made boundaries. In one of the more unique political arrangements in recent history, Norway and the former Soviet Union (now Russian Federation) have created one of the more successful internationally managed fish stock sharing systems in the world, despite high political tensions and the collapse of the Soviet Union (Gullestad et al., 2014; NMFCA, 2018). In a world with increasing international tensions, Norway and Russia's relatively steady efforts at ongoing cooperation on marine resource use in the Barents Sea through the political thicket of the twentieth century show that perhaps some good can happen if both parties are willing to continue dialogue and cooperation, no matter the circumstances.

The Barents Sea is a relatively shallow sea nestled in the far north of Europe, between the mainland of Norway and north-west Russia, the islands of the Svalbard archipelago to the west, and the Russian islands of Franz-Josef Land and Novaya Zemlya to the east (here defined as ICES areas Ia and Ib; **Figure 1**). Co-management of living resources of the Barents Sea first began in 1923 with the negotiation of seal hunting regulations, some of which are still in effect today, while research cooperation between the two countries began even earlier in the l890s (Alexseev et al., 2011). This relationship began to deepen following the establishment of the International Council for the Exploration of the Sea (ICES) in 1902, which both the USSR and Norway were a part of Alexseev et al. (2011). However, Russian participation with ICES ended in 1914 following the outbreak of WWI, and the working relationship between Norway and the USSR deteriorated until the 1950s. It was in 1958 that the region experienced a rebirth in scientific cooperation and knowledge sharing: scientists from the USSR's Polar Research Institute of Marine Fisheries and Oceanography (PINRO or "ПИНРО") visited Norway's Institute of Marine Research (IMR, or "Havforskningsinstituttet") to participate in the first ever Soviet-Norwegian Fishery Conference (Alexseev et al., 2011). The year 1977 brought new challenges with the declaration of Exclusive Economic Zones (EEZs) by both the USSR and Norway. Previously, much of the Barents Sea was high seas water, and thus in principle open for outside countries to exploit. These EEZ declarations left only a small patch of the Barents Sea at the center with the status of high seas waters (ICES area Ia, **Figure 1**), which effectively left the management of the majority of the Barents Sea in the hands of the two countries. In order to facilitate the declaration of EEZs and subsequent joint management, the Joint Norwegian-Russian Fishery Commission (JNRFC) was established in 1975-76.[1] IMR and PINRO continued conducting joint research surveys and symposia as members of the JNRFC to assess the stocks of important commercial fish, such as herring (*Clupea harengus*), haddock (*Melanogrammus aeglefinus*), and cod (*Gadus morhua*), and provide legal recommendations for quotas and stock management. Norway was therefore one of the first countries to successfully establish economic, scientific, and diplomatic cooperation with the Soviet Union during the Cold War, and this strong working relationship has generally continued into today.

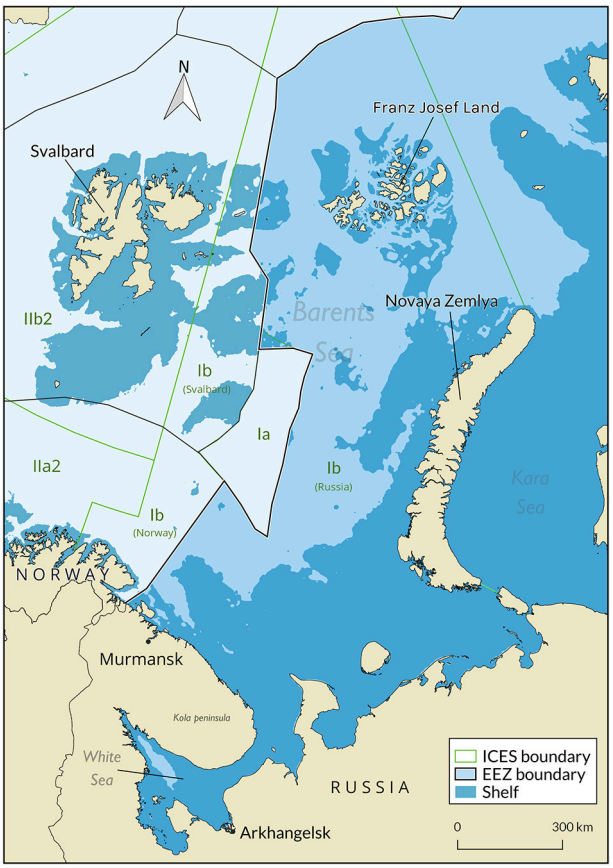


**FIGURE 1 |** Map of the Barents Sea region, including the Exclusive Economic Zones (EEZ) and shelf areas (to 200 m depth) of the Russian Federation and neighboring Norway. ICES statistical areas fall within the green boundaries. We define the Barents Sea here as corresponding to ICES areas Ia and Ib. The White Sea falls between the Kola peninsula and Arkhangelsk.

The Barents Sea and adjacent White Sea (off Arkhangelsk, **Figure 1**) were among the first areas of the world to develop large-scale commercial fishing. Over 200 fish species are found in the Barents Sea, and ∼21 species are commercially targeted by Russian fisheries (Wienerroither et al., 2011). Russian commercial fishing activities in the Barents Sea have existed since the fifteenth century, but were primarily coastal and artisanal in nature, with oar powered vessels and hand lines until the arrival of the first Russian steam trawler in 1906 (Benko and Ponomarenko, 1972; Grekov and Pavlenko, 2011). Prior to the Russian Revolution, trawling pressure came primarily from English and German trawler fleets, which outnumbered Russian trawlers four hundred to one until the 1920s (Shevelev et al., 2011). It was not until WWII that both the Russian trawl fishery and research capacity in fish stocks grew. Two main

[1]http://www.jointfish.com/.

fleets operated in the Barents region: the Arkhangelsk fleet and the Murmansk fleet (**Figure 1**). By 1913, the Arkhangelsk fleet had four steam trawlers in operation and by 1920 full-scale development of the Russian trawler fleet was underway. In 1916, the Soviet Union built the city of Murmansk to serve as an industrial and fisheries center and the Murmansk fleet was born (Grekov and Pavlenko, 2011; Shevelev et al., 2011). This, along with improvements in technology, e.g., in 1931 the first diesel operated trawler was introduced, resulted in growth of the fishing fleet from 17 industrial fishing vessels in 1927 to 562 trawlers in Murmansk alone by 1955 (Grekov and Pavlenko, 2011). From 1950 until 1980, the bottom trawl was the predominant fishing gear in the Russian Barents Sea fishery. Trawling only declined with the decline of Atlantic cod (*G. morhua*) and haddock (*M. aeglefinus*) stocks in the 1980s (Matishov et al., 2004) and the weakening of the Soviet economy, which meant cheaper, less fuel-intensive fishing techniques such as longline had to be employed (Grekov and Pavlenko, 2011). As a result of the collapse of the Soviet Union in the early 1990s, much of the Soviet distant-water fleet returned to focus on waters closer to home, including the Barents Sea (Grekov and Pavlenko, 2011; Shevelev et al., 2011). However, overall declines in Barents Sea fish stocks meant that despite the increasing fishing effort in the region there was no corresponding increase in catch (Grekov and Pavlenko, 2011; Shevelev et al., 2011; Greer, 2014). By 1996, Shevelev et al. (2011) note that "the Russian fishing industry was no longer profitable"; by 2001, fishing effort in the region had peaked and thereafter began declining (Greer, 2014); and by 2005, ∼280 trawl vessels worked the North Atlantic, less than half the number that did so in the 1950s (Grekov and Pavlenko, 2011; Shevelev et al., 2011). While the overall number of trawl vessels has declined, Russian Barents Sea fisheries are still dominated by bottom and pelagic trawls (Wienerroither et al., 2011; ICES, 2015a).

The objective of this study was to reconstruct total Russian fisheries catches (or fisheries removals allocated to Russia during the Soviet Union period) in the Barents Sea region for the period 1950-2014 using the catch reconstruction approach of Zeller et al. (2016), and builds upon and updates a previous preliminary reconstruction of Barents Sea catches by Jovanović et al. (2015). The catch reconstruction approach, first described in Bhathal (2005), develops comprehensive time-series estimates of catches missing from the reported catch baselines (i.e., unreported catches, as well as estimates of discards), and thus provides a more comprehensive picture of total removals from the marine environment. Historical time series data on total fisheries removals are crucial to fisheries management and policy, as they provide a core baseline dataset that can assist in the assessment of the populations upon which fisheries depends (Caddy and Gulland, 1983; Pauly, 2016). Furthermore, they embed any discussions on future fisheries development, management, and policy in the appropriate historical data context. While ICES stock assessment working groups have access to datasets that "outsiders" do not, and do consider some data on discards and unreported catches, these data are rarely made publicly available in sufficient detail due to confidentiality and political reasons, despite these fishes being a public resource (Zeller and Pauly, 2004). As actual total fisheries catches are generally higher than the reported data would suggest (Pauly and Zeller, 2016), we expect that the present study can assist public understanding and policy development for sustainable fisheries decisions by providing a more comprehensive historical baseline of likely total removals of fish from the Barents Sea by Russian fisheries since 1950.

# METHODS

The International Council for the Exploration of the Sea (ICES) maintains a publicly accessible database presenting reported landings by country, taxon, ICES statistical area, and year for the period 1950-present[2] (ICES, 2017b). This database does not contain data on discards and other unreported catch. There are also some years with gaps in the data, such as the 1950-1954 gap during which the Soviet Union was not a member of ICES, and gap years where catch was likely not reported for certain species despite substantial catch being reported in years previously and subsequently. After slight adjustments to the ICES catch statistics to account for these gaps and disaggregation of Russian catch from the Soviet Union, we refer to these data as "ICES baseline landings" (see **Supplementary Material** for gap adjustments and USSR disaggregation). As the aim of this study was to determine total catch, six different unreported components of catch were identified, estimated and added to these ICES baseline landings: (1) unreported stock assessment landings (addressing discrepancies between ICES working group catch and ICES reported catch), (2) unreported illegal landings (mainly the result of organized crime and/or poaching), (3) unreported artisanal landings, (4) discards, (5) recreational catch, and (6) subsistence catch. Note that international reporting requests (e.g., FAO) specifically include non-commercial (e.g., recreational) landings, but explicitly exclude discards (Pauly and Zeller, 2016). We consider this anachronistic in an era of ecosystem consideration in fisheries (Pauly and Zeller, 2016).

## Reported Landings

### Taxonomic Disaggregation

Within the ICES baseline landings data, several years included catch statistics with very coarse taxonomic resolution, i.e., "Finfishes nei," "Flatfishes nei," and "*Anarhichas*" (wolffishes). These broad "nei" (or "not elsewhere included") categories are often reported to a finer taxonomic resolution in national statistics, suggesting that "nei" categories may be an artifact of the statistical reporting or harmonization process at ICES (Pauly and Zeller, 2015). These uninformative taxonomic groupings were taxonomically disaggregated based on best-available information and conservative assumptions about which species should be included in these categories (**Table 1**). "Finfishes nei" was disaggregated into the top 10 species caught proportionally by weight, excluding major commercially targetted species (i.e., not cod, capelin, or haddock). Non-major species were chosen under the assumption that they are less likely to be identified to the species or genus level in records, while valuable or

[2]http://www.ices.dk/marine-data/dataset-collections/Pages/Fish-catch-and-stock-assessment.aspx.

**TABLE 1 |** Taxonomic disaggregation of highly uninformative pooled taxonomic groups ("nei" = not elsewhere included) in the reported catch data for Russia and the former USSR.

| Pooled group | Disaggregated species | Disaggregation (%) |
|---|---|---|
| Finfishes nei | *Boreogadus saida* | 64.0 |
| | *Sebastes* spp. | 11.0 |
| | *Anarhichas lupus* | 9.0 |
| | *Eleginus nawaga* | 4.0 |
| | *Anarhichas minor* | 3.8 |
| | *Anarhichas denticulatus* | 3.2 |
| | *Pollachius virens* | 2.5 |
| | *Salmo salar* | 1.0 |
| | *Coregonus* spp. | 1.0 |
| | *Osmerus eperlanus* | 0.5 |
| Flatfishes nei | *Pleuronectes platessa* | 55.0 |
| | *Hippoglossoides platessoides* | 20.0 |
| | *Hippoglossus hippoglossus* | 12.0 |
| | *Platichthys flesus* | 11.0 |
| | *Glyptocephalus cynoglossus* | 2.0 |
| *Anarhichas* spp. | *Anarhichas lupus* | 89.0 |
| | *Anarhichas minor* | 6.0 |
| | *Anarhichas denticulatus* | 5.0 |

commercially important species with dedicated ICES stock assessment groups likely are. "Flatfishes nei" and "*Anarhichas*" were both disaggregated proportionally by weight of landed flatfish and wolffish species, respectively.

### Spatial Disaggregation

Russian statistics for the Barents Sea have only been reported as ICES statistical area I, without subarea reference (**Figure 1**). In order to assign them to more spatially explicit locations, catch was split into each subarea: Ia (High Seas), Ib (Russian EEZ), or Ib (Norwegian EEZ, including Svalbard; **Figure 1**). Catch was split proportionally by surface area (**Table 2**). In doing so, most catch was allocated to Russia's EEZ, as that is the largest area, followed by Norwegian waters, followed by High Seas (Ia). As Norway and Russia have numerous bilateral fishing agreements, Russian fishing is indeed occurring in Norwegian waters (Nakken, 1998; FAO, 2007; ICES, 2015a). Very little information could be found on more spatially explicit fishing locations that could be applied to all data, as catch statistics are generally reported in broad geographical regions by national authorities and by ICES.

### Assignment to Commercial Fisheries Sectors: Industrial vs. Artisanal

Generally, Russian fishing activities in the Barents Sea can be divided into three main groups by fishing gear: trawl, purse seine, and longline. According to an examination of the cod fishing fleet in the Barents Sea in 2004 (WWF, 2005), ∼150 trawlers under 15 m and 200 trawlers over 15 m were active. While nearly half of the fleet is small and could be considered artisanal in nature, we considered all fishing gears that are actively moved through the water or across the seafloor while using engine power as industrial gear (or "large-scale") irrespective of vessel size, as defined in Martín (2012). Furthermore, given the heavy focus on offshore fishing by relatively large vessels throughout the Barents Sea, we considered the purse seiners and longliners as industrial as well. We therefore considered all landings reported to ICES as part of the industrial sector. Catches by artisanal (i.e., small-scale commercial) fleets were estimated as unreported catches as described below.

**TABLE 2 |** Surface areas of individual ICES subareas in the Barents Sea, including EEZ division as derived by the *Sea Around Us* (Zeller et al., 2016). The Norwegian EEZ includes Svalbard waters.

| Subarea | "Owner" | Area (km$^2$) | Area (%) |
|---|---|---|---|
| Ia | High Seas | 68,154 | 4.19 |
| Ib | Norwegian EEZ | 360,751 | 22.17 |
| Ib | Russian EEZ | 1,198,336 | 73.64 |

## Unreported Catch

Six main components of unreported catch were estimated and added to the ICES reported baseline: (1) unreported stock assessment landings from ICES Working group reports, (2) unreported illegal landings (e.g., poaching), (3) unreported artisanal landings, (4) discards, (5) recreational landings, and (6) subsistence landings. The nature of unreported landings differed between the former USSR and the Russian Federation.

### Unreported Stock Assessment Landings

Official ICES catch statistics are not corrected for unreported catches that may be included in ICES stock assessment working group reports (ICES, 2017a). We considered discrepancies between ICES publicly reported statistics and ICES Working Group reports used for stock assessment as "unreported stock assessment landings." Unreported landings were added for nine species using data from several ICES Working Group reports (ICES, 2001; 2015a; 2015b; 2015b; 2016). Unreported stock assessment landings added an average of 10% to the total reported landings.

### Unreported Illegal Landings

Unreported illegal landings, such as obtained through poaching, reflect estimates of entirely unreported landings across the fishery and are criminal in nature. Unreported illegal landings, oftentimes to avoid state control (during the Soviet era) or as a result of organized criminal activity (poaching), occurred throughout nearly the entirety of the study period (O'Hearn, 1980; WWF, 2005; FAO, 2007; Burnett et al., 2008). Historical estimates of tons of underreported catch per ton of reported catch acted as "anchor points" for years where such estimates existed in the literature. In between anchor point years, these estimates of underreporting were linearly interpolated unless otherwise stated. A more in-depth historical context behind these anchor points is presented in the discussion.

We assumed unreported illegal landings were zero from 1950 to 1959. This reflects the conservative assumption that all

landed catch was reported during the years of Stalin's rule and immediately following his death. From 1960 to 1975, unreported landings (as a percentage of reported landings) rose steadily from 0 to 33%, to reflect an estimate reported in O'Hearn (1980). This 33% rate was kept steady from 1976 until the last year of the Soviet Union (1990) and was increased thereafter to 40%, to reflect an estimate by the Norwegian Directorate of Fisheries that underreporting had reached a rate of "almost 50 per cent" (Burnett et al., 2008). As the estimate of almost 50% comes from a 2008 report, we assumed 2008 to be the last year of such high underreporting. An underreporting rate of 5% for the year 2014 was chosen given the 2015 Arctic Fisheries Working Group report estimating little to no underreporting (ICES, 2015a); for years between 2008 and 2014, the rate was linearly decreased from 40 to 5%.

The above rates of underreporting were applied to the reported baseline landings of all fish except Atlantic salmon (*Salmo salar*). According to the Working Group on North Atlantic salmon (WGNAS), illegal poaching of salmon is a "considerable" problem in the Barents and White Seas, particularly after the 1990s (ICES, 2015b). The report goes on to say that this high level of underreporting continued into the 2000s. Independent estimates of salmon poaching in the region indicate that poaching may reach underreporting levels as high as 50% (Spiridonov and Nikolaeva, 2005). As such, unreported catches for salmon followed the above unreported rates until 1991, at which point underreporting increased to 50% of reported landings and remained at that level until 2014.

## Unreported Artisanal Landings

While all ICES reported landings for Russia were categorized as industrial, Russian national data from the Russian Federation Federal State Statistics Service (федерапьная служба государственной статистики) included catch statistics by species for the White Sea separately from the Barents Sea. These data do not seem to be included in the ICES data. Russian national data for only the Barents Sea generally matched ICES statistics very well, and were thus considered to be comparable to the ICES dataset; there was no comparable match between national data and ICES data for the White Sea. Therefore, we assumed ICES baseline statistics did not include catches for the White Sea, and added the national White Sea data as unreported landings. Because the White Sea is a relatively small, sheltered, shallow body of water that is likely being fished by a smaller coastal fleet, we assumed that all landings from within the White Sea were artisanal in nature. Federal statistics were only available for the years 2010-2013, which were averaged and converted into a percentage of reported Barents Sea landings per year (i.e., 0.2%). For all years from 1950 to 2014, we therefore assumed that White Sea artisanal landings were equivalent to 0.2% of reported Russian Barents Sea landings, broken down by taxa as reported in the national data for the White Sea. These landings were designated as unreported artisanal. While artisanal fishing activity has existed in the Barents Sea region since 1950 (Shevelev et al., 2011), our estimate for the whole area is likely not a very comprehensive representation of artisanal fishing in the entire Barents Sea. We consider our approach to provide a very conservative minimal estimate of artisanal activities in these waters, and we would like to encourage further research on non-industrial fishing in the wider Barents Sea area.

## Discards

Discards are unwanted fish (bycatch) that are caught in the process of actively targeting a more desirable species, and are especially common in non-selective fishing gears such as bottom trawls. Bycatch from industrial gears are often discarded overboard and generally experience high mortality rates. While discards happen in nearly all industrial fisheries, there is as of yet no official reporting of Russian discards by fishery within the Barents Sea (ICES, 2015a).

Discards were calculated by associating a fishing gear with a primary commercially targeted species, then using independently published estimates of bycatch rates for that gear to calculate the tonnage of discards per tonnage of landed catch. Discards were therefore calculated as a percentage of total landings (reported plus unreported) by major target taxa and gear associated with that target fishery. Only the largest commercial fisheries with the best available information on gear types were chosen to calculate discards; thus, our discard estimates may be underestimating other discards, as discards likely exist for all other fish caught and reported in the Barents Sea. As gear types and discard rates change over the years with improvements in technology and with changes in regulation, the gear type and discard rates associated with each fishery varied by decade. For example, the installation of sorting grids throughout various fisheries meant that discards decreased as time went on. Not only did discards decrease overall as the decades passed, but improvements in trawling technology and better targeting also meant the overall species composition of discards changed.

The exception to calculating discards by fishing gear was the crab fishery, where a flat discard rate was applied to all crab and miscellaneous marine invertebrate catches, regardless of how they were caught. While there was insufficient information available to associate the crab fisheries with specific gears, there were multiple independent estimates of rates of bycatch within the crab fishery in general.

### *Gear types*

The *Sea Around Us* maintains a reconstructed catch database with standardized fishing gears assigned to each fishery wherever possible, and these gears were used for this reconstruction (Cashion et al., 2018). The main fisheries in the Barents can be divided into two categories: pelagic stocks and demersal stocks. Pelagic stocks include capelin (*Mallotus villosus*), herring (*C. harengus*), and polar cod (*Boreogadus saida*), all of which are primarily targeted by pelagic trawl, followed by purse seining. Demersal stocks include cod (*G. morhua*), haddock (*M. aeglefinus*), saithe (*Pollachius virens*), redfish (*Sebastes* spp.), northern shrimp (*Pandalus borealis*), wolffish (*Anarhicas* spp.), and Greenland halibut (*Reinhardtius hippoglossoides*) (Benko and Ponomarenko, 1972; Wienerroither et al., 2011; ICES, 2015a). All demersal stocks are primarily targeted by bottom trawl with the exception of the wolffish fishery, a majority of which is caught by

**TABLE 3 |** Percentage composition of catch by fishing gear types within Russian Barents Sea fisheries.

| Stock | | Pelagic trawl | Purse seine | Bottom trawl | Longline | Source |
|---|---|---|---|---|---|---|
| Pelagic | Capelin | 84 | 16 | – | – | Wienerroither et al., 2011 |
| | Herring | 84 | 16 | – | – | Wienerroither et al., 2011 |
| | Polar cod | 84 | 16 | – | – | Wienerroither et al., 2011 |
| Demersal | Cod | – | – | 93 | 7 | Wienerroither et al., 2011 |
| | | – | – | 95 | 5 | ICES, 2015a |
| | Haddock | – | – | 93 | 7 | Wienerroither et al., 2011 |
| | | – | – | 95 | 5 | ICES, 2015a |
| | Saithe | – | – | 93 | 7 | Wienerroither et al., 2011 |
| | | – | – | 100 | – | ICES, 2015a |
| | Redfish | – | – | 93 | 7 | Wienerroither et al., 2011 |
| | Northern shrimp | – | – | 100 | – | ICES, 2015a |
| | Wolffish | – | – | 40 | 60 | ICES, 2015a |
| | Greenland halibut | – | – | 90 | 10 | ICES, 2015a |

longlining. A summary of the gear types used in each fishery and the source of the information is in **Table 3**.

### *Discard rates*

Discard rates varied by fishing gear and decade, to reflect improvements in technology and changes in regulations. Six gear types were chosen and assigned to each fishery: pelagic trawl, purse seine, longline, shrimp trawl, finfish bottom trawl, and flatfish bottom trawl (**Table 4**). Previously published estimates of global fisheries discards (Alverson et al., 1994; Kelleher, 2005) were used to determine baseline discard rates for each fishery and gear type. Fishery- and location-specific estimates from Alverson et al. (1994) were used for all fisheries pre-1990. After 1990, discard rates were taken from the FAO's updated Kelleher (2005) discards estimates, and applied during years when sorting grids were introduced into various corresponding fisheries as noted in the literature. Sorting grid regulations were introduced for three fisheries during the study period: the northern shrimp trawl (1993), groundfish (including both finfishes and flatfishes) trawl (1997), and Greenland halibut flatfish trawl (2013; Dingsør, 2001; ICES, 2015a); the lower Kelleher (2005) discard rate estimates were therefore introduced in each of those fisheries during those years, respectively (**Table 4**).

For years between the older Alverson et al. (1994) rates and newer Kelleher (2005) rates, the discard rates were linearly interpolated. Only the lower, so-called "weighted" discard rates as presented in Alverson et al. (1994) and Kelleher (2005) were used, as they represent a more conservative estimate (Kelleher, 2005). Wherever possible, the gears used in geographic regions closest to the Barents Sea (e.g., "Northeast Atlantic") or targeting similar species (e.g., "North Sea shrimp trawl") were used. For a summary of changes in discard rates, see **Table 4**; for a more detailed description of how discard rates varied through time, see the **Supplementary Materials**.

### *Discard composition*

Discard composition for the entire study period was adapted from IMR/PINRO joint trawling and longlining surveys conducted between 2009 and 2012 (McBride et al., 2014). These surveys were used to develop three "baseline" species compositions that are expected to be caught when trawling or longlining for fish: pelagic trawl species; bottom trawl species; and longline species. The baseline species compositions for pelagic trawls and bottom trawls were then modified over time to reflect the adoption of sorting grids and increased mesh sizes in the trawl fisheries. For more information regarding how discard compositions changed over time, see the **Supplementary Materials**; for a full timeline outlining discard changes through time, see **Table S1**.

### *Crab discards*

After the experimental introduction of the non-native red king crab (*Paralithodes camtschaticus*) to the Barents Sea in 1961 in an attempt to start a successful crab fishery (Gjøsæter, 2009), crab fishing has slowly become more popular in the Barents Sea. Because no detailed information on bycatch in the Barents Sea crab fishery has been published, a 6.4% discard rate from a 13 year survey of a similar Bering Sea fishery was used instead (Armstrong et al., 1993). This discard rate was applied to king crabs and to miscellaneous marine invertebrates.

## Recreational Fishing

Recreational fishing has historically been popular in Russia (FAO, 2007), particularly for salmon on the Kola Peninsula in the Barents Sea region (**Figure 1**; ICES, 2012, 2015b). The ICES planning group on recreational fishing indicates that on average, recreational fishing accounts for 2–8% of a country's total reported landings (ICES, 2010). However, as there is little to no data on recreational fishing in the Barents Sea region prior to 1990, a likely conservative recreational fishing rate of 0.5% of reported landings was applied for the period 1950-1990. 1990 was likely the year when recreational fishing was first "officially" opened to foreign tourists, and it is assumed that recreational fishing increased in popularity with the increase in tourism to the region after the fall of the Soviet Union. Thus, it was assumed

**TABLE 4 |** Discard rates as a percentage of retained catch (landings) by major gear types over time for the Russian Barents Sea fisheries.

| | | | Shrimp grids | Groundfish grids | Halibut grids | |
|---|---|---|---|---|---|---|
| | **1950–1989** | **1990–1992** | **1993–1996** | **1997–2012** | **2013** | **Fisheries** |
| Pelagic trawl | 0.2 | 3.5 | 3.5 | 3.5 | 3.5 | Herring, capelin, polar cod |
| Purse seine | 24.8 | 1.2 | 1.2 | 1.2 | 1.2 | Herring, capelin, polar cod |
| Bottom trawl (finfish) | 283.8 | 283.8 | – | 19.6 | 19.6 | Cod, haddock, saithe, redfish, wolffish |
| Bottom trawl (flatfish) | 283.8 | 283.8 | – | 53.1 | 26.6 | Greenland halibut |
| Longline | 78.4 | 7.5 | 7.5 | 7.5 | 7.5 | Cod, haddock, saithe, redfish, wolffish |
| Shrimp trawl | 144 | – | 5.4 | 5.4 | 5.4 | Northern shrimp |

*Dashes indicate "transition years" between Alverson et al. (1994) and Kelleher (2005) rates during which discard rates were linearly interpolated. 1993, 1997, and 2013 were years during which sorting grids were introduced in the northern shrimp, groundfish, and Greenland halibut fisheries, respectively.*

that from 1991 onwards, the lower end estimate of 2% from ICES (2010) was chosen for calculating recreational catch.

The exception to the data-poor recreational sector in Russia's Barents Sea waters is recreationally caught Atlantic salmon (*S. salar*). Recreational catches of salmon after 1991 are exceptionally well documented by the Working Group on North Atlantic salmon (WGNAS; ICES, 2015b). Data on the number of salmon that were caught and then retained each year in the recreational fishery were obtained from the 2015 Working Group report (ICES, 2015b). The average annual mean fork lengths and whole weights of Atlantic salmon, for all sea ages, for each year from 1991 to 2012, were published by the National Oceanic and Atmospheric Administration (NOAA) and used to convert the number of salmon caught to the weight of salmon caught (Sheehan et al., 2013). For the years 2013 and 2014, the same weight as in 2012 was used.

After calculating the total recreational landings per year, the estimated catch of salmon for that year was subtracted from the total. The recreational catch without salmon was then split evenly between seven commonly targeted recreational species described on numerous Russian fishing websites: cod (*G. morhua*), navaga (*Eleginus nawaga*), polar cod (*B. saida*), wolffish (*Anarhicas lupus*), haddock (*M. aeglefinus*), saithe (*P. virens*), and pollack (*Pollachius pollachius*).

### Subsistence Fishing

While the Soviet Union had public cafeterias to ensure nobody went hungry, food shortages were common and diets were supplemented with home cooking. However, obtaining groceries often involved waiting in long lines and paying exorbitant prices. It is likely that non-commercial catching of fish for family consumption (subsistence) complemented the rural diet, particularly in coastal communities.

Catch from subsistence fishing was calculated in two steps: first, the Russian rural population of the Barents Sea was estimated; second, this population estimate was multiplied by per-capita estimates of fish consumption in the USSR and Russia. Per-capita consumption rates were adjusted through time to reflect changes that are noted in the literature. Population data for the period from 1950 to 2001 were obtained from Populstat[3], while from 2002-onwards Russian census data for the years 2002 and 2010 were used. For the years between 2002 and 2010, population data were interpolated; for the years 2010 to 2014, estimates of total population size provided by the Federal State Statistics Service[4] were used. For both per-capita consumption rates and population, estimates in years between data points were linearly interpolated. See **Supplementary Materials** for more details.

In order to estimate the amount of fish consumed that were actually caught via subsistence fishing (as opposed to being purchased at market), we relied on the conservative estimate derived in the Russian Black Sea fisheries reconstruction (Divovich et al., 2015). Thus, it was assumed that 5% of all fish consumed was caught via subsistence fishing until just after the dissolution of the USSR (1992), thereafter increasing to 20% by 1995 and 26% by 2002 to reflect a decreased reliance on government food services and the increased food costs associated with the collapse of state subsidies (Divovich et al., 2015). The derived per-capita subsistence catch rate was then applied to the estimated rural population around the Barents Sea to estimate a likely total tonnage of subsistence fishing. The species disaggregation for subsistence fish was kept the same as in recreational fishing, as both are small-scale fisheries that employ similar methods of fishing. We recognize that there may be overlaps between recreational and subsistence fishing.

## RESULTS

Total reconstructed landings (i.e., retained, landed catch that does not include discards) averaged 473,000 t·year$^{-1}$ during the 1950s and 1960s, peaking at ∼1.5 million tons in 1977, and declining to a low point of 92,000 tons in 1990 before rebounding to average annual landings of 457,000 t·year$^{-1}$ by 2014 (**Figure 2A**). Landings fluctuated substantially over the time period, with peaks and declines in landings occurring roughly every decade until the mid-2000s, after which landings remained more stable. Officially reported data (accounting for landings only, and excluding discards) under-represented actual total landings for most years, although for the earliest years (1950s)

[3]http://populstat.info/.

[4]http://www.gks.ru/wps/wcm/connect/rosstat_main/rosstat/ru/statistics/population/demography/.

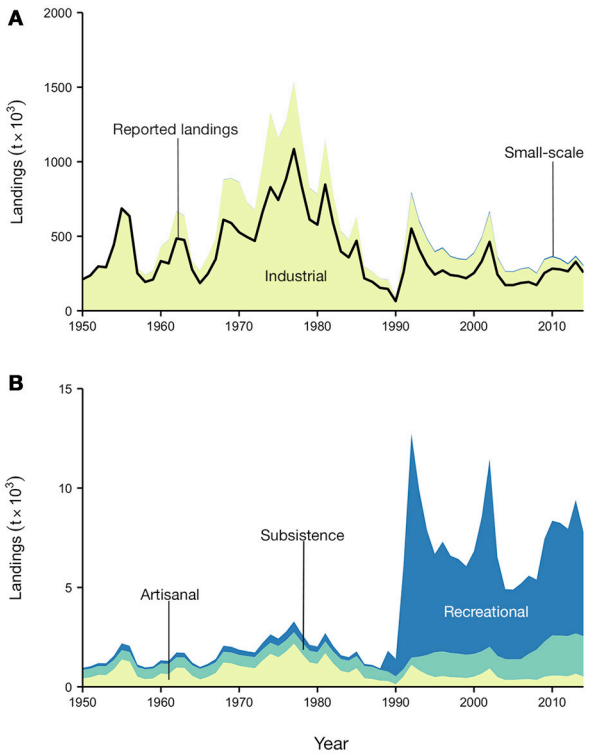


**FIGURE 2 |** Reconstructed landings for Russia in the Barents Sea with **(A)** total reconstructed landings from 1950 to 2014 by sector. Small-scale sectors (artisanal, recreational, subsistence) represent less than 1% of landings. Reported data are overlaid as a line graph. **(B)** Unreported artisanal, recreational, and subsistence landings, i.e., the "small-scale" component from **(A)**, here expanded for clarity.

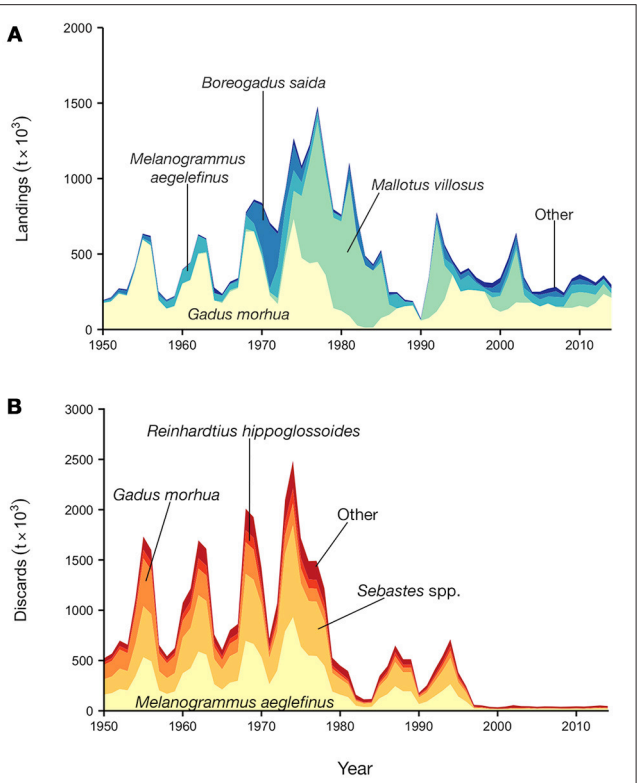


**FIGURE 3 |** Taxonomic composition of Russian Barents Sea fisheries catches with **(A)** total landings by the four major landed taxa and all other taxa pooled ($n = 59$); and **(B)** total discards by the four major discarded taxa and all other taxa pooled ($n = 19$).

and more recent years (mid-2010s), they seem to account more comprehensively for actual landings (**Figure 2A**).

A relatively small fraction of reconstructed landings was deemed to be small-scale in nature (**Figure 2A**), these being artisanal, recreational, and subsistence landings (all deemed unreported, **Figure 2B**). Combined, these three small-scale sectors averaged less than 1% of the total reconstructed landings. Landings in these three sectors remained relatively steady at an average of 1,700 t·year$^{-1}$ until 1991, which was the year the Russian Federation was declared open to outsiders. At this point, recreational fishing increased dramatically to a total of nearly 12,000 tons in 1992; thereafter, unreported small-scale landings, while varying widely, averaged around 5,600 t·year$^{-1}$ (**Figure 2B**).

Landings throughout the entire time period were dominated by Atlantic cod (*G. morhua*) and capelin (*M. villosus*), which largely drive catch patterns in the Barents (**Figure 3A**). By the mid-late 1970s, declines in cod stocks resulted in an increased demand for capelin. This demand for capelin rapidly pushed the total fisheries landings higher each year until the 1977 peak. Capelin landings thereafter declined until the first collapse of the stock in 1986-1990, second collapse in 1993-1998, and most recent stock collapse in 2004-2006 (**Figure 3A**). Haddock (*M. aeglefinus*), usually caught in fisheries targeting cod, followed similar patterns as the cod catch, while polar cod (*B. saida*) has its own dedicated smaller pelagic trawl fishery. In all cases, regardless of taxon, landings declined after the late 1970s peak. The "Other" category in **Figure 3A** consists of an additional 59 individual taxonomic groups, which on average accounted for ∼12% of the total landings (**Figure 3A**). For individual taxon figures, see **Supplementary Figure S2**.

When considering total catches (i.e., including discards) over the 65 years examined here, the total reconstructed catch (77.2 million tons) was approximately three times higher than the total reported catch (25 million tons), a difference of over 52 million tons (**Figure 4**). While unreported landings were a component of this difference in catch (unreported landings accounted for 12% of total reconstructed catch), the 42.7 million tons of discards by far dominated: discards accounted for 55% of total reconstructed catch. Reported landings, then, accounted for only 33% of reconstructed catch (**Table 5**). Thus, total Russian catch (including discarded catch) in the Barents Sea increased from an average of 1.2 million t·year$^{-1}$ in the early 1950s to a peak of 3.8 million tons in 1974, before declining to 330,000 t·year$^{-1}$ by the mid-2010s (**Figure 4**).

Discards were a substantial component of total Russian catch in the Barents Sea until the wide-scale adoption of sorting grids and bycatch-reduction technology starting in the 1980s

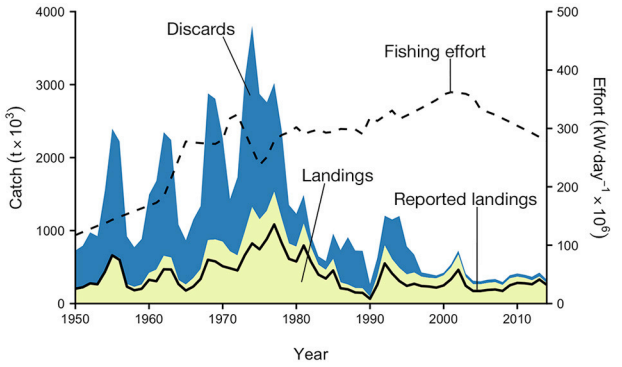


**FIGURE 4 |** Total reconstructed Russian catch in the Barents Sea, including discards and landings. Reported data (landings only) are overlaid as a black line graph. Fishing effort by the Russian fleet in the Barents Sea from Greer (2014) are overlaid as a secondary black dashed line graph. Note the separate y-axis scales for catch (t·year$^{-1}$) and effort (kW·day$^{-1}$).

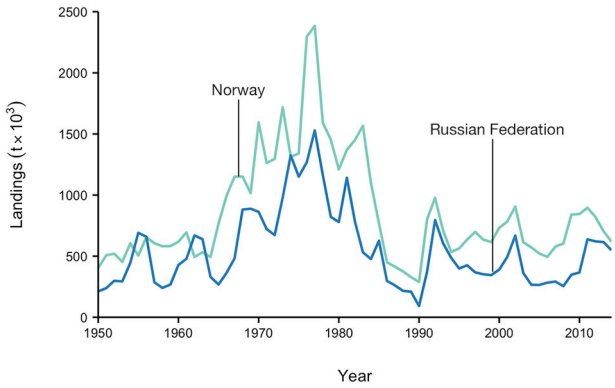


**FIGURE 5 |** Total reconstructed landings in the Barents Sea (ICES areas Ia and Ib only) by Norwegian (Nedreaas et al., 2015) and Russian fisheries.

**TABLE 5 |** Summary of total reconstructed catch for the entire 1950-2014 period, broken down by component.

| | Catch (tons) | Percentage |
|---|---|---|
| **Reported landings** | 25,073,804 | 32.5 |
| **Unreported landings** | 9,439,264 | 12.2 |
| *Industrial* | *9,191,066* | *11.9* |
| *Recreational* | *145,505* | *0.2* |
| *Subsistence* | *52,545* | *0.1* |
| *Artisanal* | *50,148* | *< 0.1* |
| **Discards** | 42,716,436 | 55.3 |
| Total | 77,229,503 | 100 |

*Fishing sectors are italicized.*

(**Figure 4**). Up until the peak in catches in 1977, discards represented the majority of Russian fisheries catch (greater than 50%). However, after the 1977 peak, discards began to decline. The major driver for this decline was the decrease in discard rates for purse seiners, longliners, and shrimp trawlers (**Table 4**). The introduction of sorting grids in the shrimp trawl fishery in 1993, followed by grids in the groundfish fisheries in 1997, meant that discards declined to an average of 11% of total catch by the early 2000s (**Figure 4**). Bottom trawling gear was the source of a majority of discards.

Discarded catches were dominated primarily by groundfish taxa, including haddock (*M. aeglefinus*), redfish (*Sebastes* spp.), and cod (*G. morhua,* **Figure 3B**). All three species are prominent bycatch species in the cod bottom trawl fishery. The widely distributed Greenland halibut (*R. hippoglossoides*) is the fourth most discarded species. At least an additional 19 other taxonomic groups (comprising the "Other" category) contribute to discarding, making up ∼11% of total discards (**Figure 3B**). For individual taxon figures, see **Supplementary Figure S3**.

# DISCUSSION

The Barents Sea has historically been a rich fishing ground, with both Russia and Norway taking advantage of the natural abundance of the region. In the second half of the twentieth century, however, Russian fisheries in the Barents Sea have declined since a historical peak in the late 1970s, which is consistent with other findings indicating that global catch has peaked in the last decades of the twentieth century and is now declining (Pauly and Zeller, 2016). Historical patterns of Russian landings from the Barents Sea are notably quite similar to independently reconstructed Norwegian landings in the region (**Figure 5**; Nedreaas et al., 2015). Given the long history of co-management of Barents Sea resources and the 50–50 quota split agreed upon by the Joint Norwegian-Russian Fisheries Commission, this is not entirely unexpected (Holm and Nielsen, 2007). However, it is also indicative that overall declines in Barents Sea stock abundances are affecting both Russian and Norwegian fisheries equally (Matishov et al., 2004), and addressing any fisheries declines in the region must be tackled just as equally (NMFCA, 2018). In the past, the Joint Norwegian-Russian Fishery Commission has done this successfully (Alexseev et al., 2011; Gullestad et al., 2014), and reconstructed catch notably improved after the 1980s decline for both Russian and Norwegian fisheries.

## Historical Context

### The Black Market

The planned nature of the former Soviet economy was designed to allocate goods and services as effectively as possible across all sectors of Russian society. During the Stalin years in the first half of the 1950s, harsh authoritarian rule likely prevented the underground economy from thriving. After Stalin's death, however, widespread corruption and a weak economy led to the steady rise of the Soviet "second" or "shadow" economy—i.e., the black market. The black market was so important to maintaining Russians' access to goods and services that unregulated and illegal economic activities were pervasive in all sectors of the economy.

Nearly a third of all food purchased for the home was done so via this black market (Sampson, 1987), and nearly a quarter of the fish produced entered this black market (O'Hearn, 1980).

Soviet fisheries were not immune to this pervasive corruption. Illegal underreporting of catch began to steadily rise following Stalin's death in 1953 and the subsequent loosening of authoritarian control. The government, however, was not ignorant of underreporting; in fact, as one Soviet official noted, "the government knows exactly who is dealing in what—arrests are only made when there is some larger political reason," and data on fish and game in particular was "very good" (O'Hearn, 1980). In reports O'Hearn found in the Soviet press from the 1980s, Soviet observers lamenting the lack of environmental oversight commented on the "painfully large number" of poachers using the black market for personal gain. Small fines for poaching, along with the opportunity to fetch up to 4 to 10 times the "official" Soviet price, meant that poaching was commonplace throughout Soviet fisheries (O'Hearn, 1980). It was standard practice for fishers to first offer catch on the black market and then officially hand in the rest, and it was estimated that by the 1980s, roughly 25% of total commercial catch was meant for the black market. Official Soviet reports note that unreported landings may have been as high as 267% of reported catch (O'Hearn, 1980). To remain conservative, the lower estimate of 25% of total catch, or one third of reported catch, was chosen in the present study for calculating unreported commercial catch during this time period. It is possible that our study therefore underestimated actual catches during the Soviet period.

Following the dissolution of the Soviet Union, underreporting of catch only increased further in all of the former Soviet republics. Rates of illegal fishing increased as a result of the sudden collapse of Soviet regulations and controls and the opening of the market to the outside world as the iron curtain lifted (FAO, 2007). It is during this period from the late 1990s to the early 2000s that the Norwegian Directorate of Fisheries began apprehending Russian fishing vessels in the Barents Sea in order to enforce bilateral quotas and reported their conservative estimate of overfishing "of almost 50 per cent" by Russian ships in the Barents Sea (Burnett et al., 2008).

More recently, reports of illegal catch and underreporting have substantially decreased. This is mostly a result of greater cooperation and enforcement on the part of the Joint Norwegian-Russian Fisheries Commission. In fact, one of the most recent Arctic Fisheries Working Group reports estimates that there has been little to no illegal or unreported commercial catch in recent years (ICES, 2015a). In the case of cod in particular, reports from Norwegian-Russian analysis groups indicate that actual catches of cod have roughly matched officially reported landings of cod since 2009 (ICES, 2015a).

Our conservative estimates of unreported black-market landings during the Soviet era and immediately post-Soviet collapse has interesting implications for discards. Because discards are calculated as a proportion of both reported and unreported landed catch, calculated discards would have more than doubled for the time period if a higher rate of landings underreporting would have been applied, without any change in fishing effort. The subsequent collapse of certain fisheries (such as cod and capelin) could then potentially be attributed not only to the high rate of discarding in Soviet fisheries, but to a high rate of unreported catch as well. Future adjustments and improvements upon this catch reconstruction should aim to refine this estimate of underreporting in Soviet fisheries.

## Patterns of Catch

The Barents Sea has experienced considerable fluctuations in both stock abundances and catch that has been documented by the Norwegians as early as 1860, if not earlier (Alexseev et al., 2011). In particular, the capelin stock has been known to be highly variable (Gjøsæter, 2009). Indeed, these large natural variations in capelin are one of the primary reasons fisheries scientists first came to research the Barents Sea (Alexseev et al., 2011). Similar fluctuations in cod, haddock, and saithe catches in the White Sea have been documented as well (Alexseev et al., 2011). Typically, these fluctuations are the result of abiotic factors unique to the biogeography of the region, such as the nutrient load of the system after winter (Matishov et al., 2004). These historical trends appear to have continued into the present day given the fluctuations in capelin and cod catch (**Figure 3A**).

Reported landings of cod in the earlier period of this study (1950-1980) before the stock collapse exhibit regular periodicity, which in turn drive the periodicity behind the majority of unreported landings and discards (**Figures 3A,B**). This periodicity has been well documented in the literature, where it has been found that the Barents Sea cod stock fluctuates in harmony with the Kola temperature cycle (Nakken, 1994; Yndestad, 2003; Ottersen et al., 2014). However, the regular rise and fall of reported catch appears to be unusual and does not closely match any cyclical trends of Norwegian cod catch in the region (**Figure 6**), and could potentially be driven by misreporting to ICES by the former Soviet Union. It remains to be determined if the substantial redirection of (unmonitored) catches to the black market may be a contributing factor to the unusually large fluctuations seen in USSR-reported data on

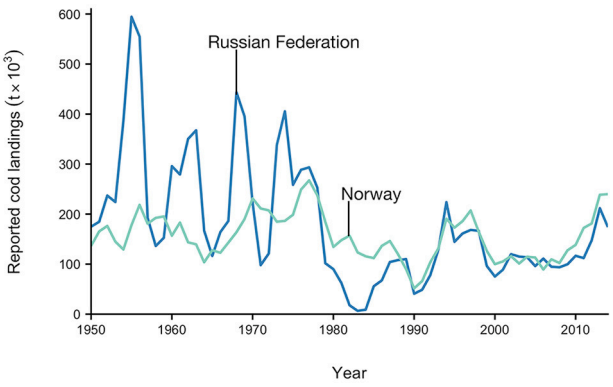


**FIGURE 6 |** Reported landings of cod (*Gadus morhua*) by both Norway and Russia in the Barents Sea. Norwegian reported landings of Barents Sea cod do not exhibit fluctuations in landings to the same degree that Russian reported landings of cod do.

cod catches in the first 3 decades of the present time series (**Supplementary Figure S1**).

### Trawling

Russian fisheries in the Barents are heavily dominated by bottom and pelagic trawling. Trawling had already been established by the 1920s but became especially well developed by the 1950s (Grekov and Pavlenko, 2011; Shevelev et al., 2011) and only intensified through the 1960s-1970s. Initially, trawls primarily targeted cod and other demersal fish stocks, while capelin and herring were only caught as baitfish. As trawling intensified, however, these conventional stocks declined and both Norway and the Soviet Union began to develop purse seine and pelagic trawl fisheries for the industrial targeting of capelin in the Barents Sea (Gjøsæter, 2009). Both pelagic and bottom trawling continued to dominate Russian fisheries, while Norwegians steadily developed longline fisheries at an industrial scale (Gjøsæter, 2009). The first Russian automated longliner, borrowed from well-established Norwegian technology, was only introduced into the Russian fishery in 1982 (Gjøsæter, 2009). By the 1990s, the collapse of the Soviet Union, with the associated collapse of the subsidies system and resulting economic downturn, meant that there was a reduction of trawling effort. Trawlers required more fuel and active fishing time, and were thus more expensive to operate. This led to an overall reduction in catch along with marginal increases in the number of longliners in the Russian Barents Sea fishery (Grekov and Pavlenko, 2011). However, even to the present day, trawlers still dominate the Russian fleet, accounting for around 90% of total Russian catch in the Barents Sea (Nakken, 1998; Grekov and Pavlenko, 2011; Wienerroither et al., 2011; ICES, 2015a).

Recent declines in catch beginning in the 1970s are strongly tied to overexploitation (Matishov et al., 2004; Pavlovich, 2016). Given that Norwegian and Russian researchers and government bodies alike acknowledge overexploitation and discarding of underage fish in the 1970s-1980s as a primary cause for the decline of both pelagic and demersal stocks, including cod (Nakken, 1994; Gullestad et al., 2014), haddock (Kiseleva and Nichols, 2016), redfish (McBride et al., 2014) herring (Gjøsæter, 1995), and capelin (Beverton, 1990; Hjermann et al., 2004), it is not unreasonable to assume other stocks were affected by the excessive fishing effort in the region as well (**Figure 4**). Modern trawling technology is notorious for scooping up entire schools of fish, with midwater and bottom trawl fleets equipped with immense nets that can reach over 100 m in width and several hundred meters in length (Morgan and Chuenpagdee, 2003) and electronics such as echosounders, gyro-compasses, and radio direction finders (introduced into the Barents Sea fishing fleets in the 1950s; Shevelev et al., 2011), all designed to catch as many tons of fish as possible in one trip. Unless considerably larger mesh sizes are introduced, nets capture all age-classes of a stock, preventing any stock recovery let alone growth in the coming years, as happened with the Barents Sea herring and capelin stocks (Beverton, 1990; Alexseev et al., 2011; Shevelev et al., 2011). Bottom trawling, in particular, is known to be highly destructive, decimating slow-growing deep-water stocks of fish and damaging the benthic habitat structures that they may depend on (Løkkeborg and Fosså, 2011; Norse et al., 2012; Puig et al., 2012). The high rates of both pelagic and bottom trawling in combination with high rates of discarding as compared to the Norwegian fleet (Nedreaas et al., 2015) may therefore have contributed to the rapid declines of stocks in the Barents Sea in the 1970s-1980s.

## Discarding

While unreported fishing is occurring in both countries, it does not appear to substantially differentiate the total amount of catch landed between the two countries (Nedreaas et al., 2015). The largest discrepancy in total catch between the two countries is instead primarily due to the high amount of discarding within the Russian fishery, as Russian fisheries primarily employ trawlers (rather than longliners; Nakken, 1998; Wienerroither et al., 2011; McBride et al., 2014). Bottom trawlers are especially well-known for being the most non-selective fishing gear, and our study is consistent with global findings that discarding is dominated by bottom trawling gear (Cashion et al., 2018).

Barents Sea discards seem primarily composed of haddock, redfish, and cod that were most likely discarded as a result of being underage or undersized (Spiridonov and Nikolaeva, 2005; Gullestad et al., 2014; ICES, 2015c). Nakken (1994) notes that in the 1980s, discards of cod only increased due to the poor condition of the fish—many of which were too small—which only exacerbated the corrosive cycle of discarding. Reconstructed discards indicate that after the widespread adoption of larger mesh sizes and sorting grids in the 1990s, discards declined considerably, which likely played an important role in the subsequent recovery of capelin, cod, and redfish stocks in the 1990s and 2000s. Redfish species have historically been particularly hard-hit by discarding practices, with golden redfish (*Sebastes marinus*) listed on the Norwegian endangered species list in 2010 and beaked redfish (*Sebastes mentella*) only recently showing signs of stock recovery as a result of improvements to trawling gear in the northern shrimp fishery (Wienerroither et al., 2011; McBride et al., 2014).

The discrepancy in discarding between the two countries may further be driven by the fact that discarding dead or dying cod and haddock has been illegal in Norway since 1987, while discarding has been banned (with some exemptions) for all fishes since 2009 (Gullestad et al., 2014; Ottemo, 2017; NMFCA, 2018). On the other hand, this may also explain why Norway's landed catch in the region is higher than Russia's: Norway simply may not be discarding as much of their catch (**Figure 5**). It has been noted that while discarding has been substantially reduced in the Russian waters of the Barents Sea, it is still a problem (Spiridonov and Nikolaeva, 2005; Burnett et al., 2008). While the Norwegian Directorate of Fisheries says that Russia has "discard regulations" in place for the Barents Sea cod, it is not clear that there is any explicit anti-discarding action in Russia aside from sorting grids (Gullestad et al., 2014). The European Union introduced the concept of a blanket ban on discarding in 2015[5], including in Russian waters within the Baltic (Bekyashev,

[5]https://ec.europa.eu/fisheries/cfp/fishing_rules/discards_en.

2017). Given the discard bans of its neighbors, including within its own waters, these regulations may have future implications in Russian Barents waters: a well-enforced discard ban by the Russian government would clearly benefit not only the shared fish stocks within Russian waters, but also Russian fleets.

## Limitations

Small-scale fisheries are notoriously data deficient (Pauly and Charles, 2015; Zeller et al., 2015; Pauly and Zeller, 2016), and those of the Barents Sea are no exception. Numerous assumptions were made in our study while estimating artisanal, recreational, and subsistence fishing. While we are confident that our estimates are conservative and not overestimates, future research should further refine reconstructed small-scale fisheries removals.

The Barents Sea ecosystem today faces additional threats, being in the rapidly warming Arctic region (Johannessen et al., 2004; Drinkwater et al., 2011; Stige and Kvile, 2017). While catch has certainly declined in part due to the intense historical fishing pressure in the region, there are likely other factors at play, and it is uncertain exactly to what degree fluctuations in catch are the result of variable or unsustainably high fishing mortality or from other abiotic or climatic factors. There is evidence that species composition in the Barents Sea is shifting as communities move farther north with the warming waters (Kortsch et al., 2012; Frainer et al., 2017). In addition, the Barents Sea is not unaffected by the scourge of introduced species invasions, including the deliberate introduction of red king crab (*Paralithodes camtschaticus*), which can result in changes in food web, trophic, and community structure (Pedersen et al., 2018). As such, both climate change and introduced species may be contributing to changes in catch and catch composition that this study could not address.

# CONCLUSIONS

The rise of industrial trawling in the Russian Barents Sea fisheries during the second half of the twentieth century came at an unfortunate price: a monumental five-fold increase in discards between 1950 and the mid-1970s. This, combined with steadily rising fishing effort in the region during the first five decades, resulted in numerous stock collapses and associated declines in catches. The subsequent poor state of the cod stock in the 1980s spurred one of the more successful jointly managed straddling fish stock management systems in recent history, and played a key role in the decline in discards by the 1980s. While reducing discards plays an important role in stock recovery (Matishov et al., 2004; Zeller et al., 2018), it is only with the cooperation of all parties involved and precautionary, long-term sustainable management that the recovery of the shared Barents Sea resources is possible (Misund et al., 2011). Preservation of the cod stock in the Barents Sea was the primary impetus behind this steady and impressive cooperative effort, with both Russia and Norway—two countries with major cultural and political differences—in agreement on closing fishing areas and reducing discards as a fisheries management strategy for cod recovery (Gullestad et al., 2014; Ottemo, 2017). It is in this sense that the cooperative effort to rebuild and manage stocks between both Russia and Norway is remarkable.

# AUTHOR CONTRIBUTIONS

SP reconstructed the catch, and SP and DZ prepared the manuscript.

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# SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2018.00266/full#supplementary-material

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