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ADAPTIVE FLYWAY MANAGEMENT PROGRAMME FOR THE RUSSIA/GERMANY & NETHERLANDS POPULATION OF THE BARNACLE GOOSE *BRANTA LEUCOPSIS*

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The 5th Meeting of the AEWA European Goose Management International Working Group is being hosted remotely, in an online conference format.

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List of acronyms and abbreviations

AEWA	Agreement on the Conservation of African-Eurasian Migratory Waterbirds
AFMP	Adaptive Flyway Management Programme
CMS	Convention on the Conservation of Migratory Species of Wild Animals
EC	European Commission
EGM IWG	European Goose Management International Working Group
EGM IWG4	The 4th meeting of the EGM IWG
EGMP	(AEWA) European Goose Management Platform
FCS	Favourable Conservation Status
FRH	Favourable Reference Habitat (in sense of ‘habitat for the species’ DG Environment, 2017)
FRP	Favourable Reference Population
FRR	Favourable Reference Range
ISSMP	International Single Species Management Plan (Jensen *et al.*, 2018)
MOP	Meeting of the Parties
MU	Management Unit

Introduction

The International Single Species Management Plan (ISSMP) for the Barnacle Goose *Branta leucopsis* (Jensen et al., 2018) was developed according to Paragraph 4.3.4 of the AEWA's Annex 3. This provides for developing ISSMPs for populations which cause significant damage, in particular, to crops and fisheries. In addition, it responds to AEWA Resolution 6.4, which requested the establishment of a multispecies goose management platform and process to address the sustainable use of goose populations and to provide for the resolution of human-goose conflicts, targeting as a matter of priority Barnacle and Greylag Geese.

The ISSMP for the Barnacle Goose was adopted at the 7th Session of the Meeting of the Parties to AEWA (MOP7), 4-8 December 2018 in Durban, South Africa. The ISSMP provides a mandate for developing population-specific Adaptive Flyway Management Programmes (AFMP) for each population of the Barnacle Goose, recognising that there are regional differences in migratory behaviour and the human-wildlife conflicts involved in some population. This AFMP shall be formally adopted by the European Goose Management International Working Group (EGM IWG) and then reviewed periodically.

A document on the process and the outline for the development of the Adaptive Flyway Management Programme (AFMP) for the Russia/Germany & Netherlands population of the Barnacle Goose (Doc. AEWA/EGMIWG/4.13/CORR. 1[2]) was presented and adopted at the 4th Meeting of the EGM IWG on 18-20 June 2019, Perth, UK (EGM IWG4). This document follows the agreed outline of the AFMPs. The purpose of this AFMP is to establish an agreement amongst Range States of the Russia/Germany & Netherlands population of Barnacle Goose on the implementation of those activities in the Barnacle Goose ISSMP that require coordination at the population and/or Management Unit (MU) level. Specifically, this AFMP addresses the following issues:

1) Definition of MUs (Chapter 1);
2) Definition of Favourable Reference Values (FRVs) for the population and its MUs (Chapter 2);
3) Provide a consolidated assessment of damages and risks caused by this population of Barnacle Goose (Annexes 2 and 4);
4) Establish protocols to assess the cumulative impact of all off-take including both derogations and legal hunting, where allowed (Chapter 3);
5) Establish indicators (Chapter 4 and Annex 5).

The implementation of further activities of the Barnacle Goose ISSMP is elaborated in the population-specific workplans. Annex 1 provides guidance on developing such workplans.

It should be noted, however, that Range States remain responsible for national planning and implementation within the framework of the ISSMP including their derogation measures under the provisions of Articles 9 of the Birds Directive and the Bern Convention.

This AFMP covers the period of 2020 – 2026.

[2]https://egmp.aewa.info/sites/default/files/meeting_files/documents/AEWA_EGM_IWG_4_13_BG_AFMP_Corr_1.pdf

1. Definitions of Management Units (MUs)

Management unit definitions were agreed at the EGM IWG4 in June 2019 (see document Doc. AEWA/EGMIWG/4.15[3]). Accordingly, three management units are recognised, all wintering in the same range in the Netherlands, Belgium, Germany, Denmark and south Sweden[4]:

MU1: The arctic Russian breeding population (migratory).

MU2: The temperate Baltic breeding population (migratory).

MU3: The temperate North Sea breeding population, breeding in the Netherlands, Germany and south-west Denmark (considered sedentary)

2. Definitions of Favourable Reference Values (FRVs)

Following EGM IWG4, a revised document setting out the principles of defining FRVs for the Barnacle Goose was circulated on 7 October 2019. This version was revised based on written feedback from Range States and a workshop held with the European Commission (EC) and EU Member States on 31 January 2020 in Brussels. A final version of the document was circulated to the EGM IWG on 24 March 2020 (AEWA/EGMIWG/Inf.5.11[5]).

Favourable Reference Populations (FRPs)

The FRP is proposed to be set at the Agreement Value (i.e. around the year 2000) level, i.e. **380,000 individuals for the entire wintering population**. This represents the situation when the population has exceeded the carrying capacity of the staging areas in the Baltic (Eichhorn *et al.*, 2009).

The Favourable Reference Populations for the breeding season in the **Baltic** and **North Sea MUs (MU2** and **MU3)** were to be defined by each Range States that recognises the Barnacle Goose as a naturally occurring breeding species. If a Range State has not communicated any values to the AEWA Secretariat or it has not notified it that species is not a naturally occurring breeding species in its territory, the best single value, or if it was not given, the geometric mean of the minimum and maximum population estimates from the country's EU Birds Directive Article 12 report for the 2013 – 2018 period were taken as breeding FRPs. The FRP for MU1 is 113,000 pairs, for each **MU2** and **MU3 it** is **12,000 pairs** and for the whole population is 137,000 pairs (Table 1).

[3]https://egmp.aewa.info/sites/default/files/meeting_files/documents/AEWA_EGM_IWG_4_15_Def_BG_MUs.pdf

[4] Norway and Belgium were removed from MU2 and MU3, respectively, because these countries do not recognise their breeding populations as naturally occurring ones.

[5]https://egmp.aewa.info/sites/default/files/meeting_files/information_documents/AEWA_EGM_IWG5_Inf_5_11_FRVs_BG.pdf

Table 1. Breeding FRP values for the three management units

Country	Breeding FRP (in pairs)	Notes	Wintering FRP (in individuals)
Russia	112,927	Calculated as 380,000/2.78 – (FRPs MU2 & MU3)	
MU1 total	***112,927***		***n.a.***
Denmark	2,000	FRP reported by the government	
Estonia	89	National BD Art. 12 report[6]	
Finland	7,000	National BD Art. 12 report[7]	
Norway	n.a.	It is not recognised as a naturally occurring breeding species by the government.	
Sweden	2,900	National BD Art. 12 report [8]	41
MU2 total	***11,989***		***n.a.***
Belgium	n.a.	It is not recognised as a naturally occurring breeding species by the government.	555
Germany	775	Source: National BD Art. 12 report[9]	83,471
Netherlands	11,000	FRP reported by the government	284,686
MU3 total	***11,775***		
Population total	***136,691***		***380,000***

Keys: n.a.: not applicable

It is proposed to allocate the FRP for the wintering season amongst the countries according to the distribution of wintering numbers in 2000 based on Koffijberg *et al.* (2020) because that reflects the situation when AEWA came into force (Table 1). However, it is recognised that the winter distribution of the population is likely to change as winters are getting milder. Therefore, the assessment of the wintering FRP should focus on the population as a whole. The non-breeding FRPs per MU are not presented because it is only possible to count the entire population in winter when individuals from different MUs mix.

Favourable Reference Range (FRR)

[6] http://cdr.eionet.europa.eu/Converters/run_conversion?file=ee/eu/art12/envxa2bfg/EE_birds_reports_20191018-140734.xml&conv=612&source=remote#A045-C_B

[7] http://cdr.eionet.europa.eu/Converters/run_conversion?file=fi/eu/art12/envxabcra/FI_birds_reports_20191031-102330.xml&conv=612&source=remote#A045-C_B

[8] http://cdr.eionet.europa.eu/Converters/run_conversion?file=se/eu/art12/envxbcxqa/SE_birds_reports_20191031-150346.xml&conv=612&source=remote#A045-C_B

[9] http://cdr.eionet.europa.eu/Converters/run_conversion?file=de/eu/art12/envxztrqw/DE_birds_reports.xml&conv=612&source=remote#A045-C_W

The FRRs for both the breeding and the non-breeding seasons were to be set by the Range States based on the distribution in the 2013-2018 reporting period using the range method (DG Environment, 2017, pp. 125-128). This period is used to establish the FRRs because of the CMS definition of the FRR[10] and available EU guidance (DG Environment, 2013, p. 15, 2017, p. 48).

Unless reported otherwise, the distribution area from the country's EU Birds Directive Article 12 report for the 2013 – 2018 period, is used as the FRR for the breeding season. It should be noted that this is different from the range method agreed to be used on 31 January 2020 at the meeting with the EC and EU Member States. Unfortunately, the EU Article 12 reporting collect information only on breeding distribution although the range definition of CMS[11] includes the entire annual cycle of a species and the guidance for FRR takes a similar approach (DG Environment, 2017, pp. 165-166). Therefore, it is only possible to establish the FRR for the non-breeding season based on additional reporting by the Range States. The available range information is summarised in Table 2.

The FRR for the **breeding season** for MU1 is set at 112,500 km^2, for MU2 at 62,500 km^2, for MU3 at 41,500 km^2 and for the whole population at 216,500 km^2 after rounding.

For the **non-breeding season** it was not possible to define the FRR because several Range States did not provide this information.

[10] "the range of the migratory species is neither currently being reduced, nor is likely to be reduced" (see Article I.c.(2) of the CMS Convention Text).

[11] "Range" means all the areas of land or water that a migratory species inhabits, stays in temporarily, crosses or overflies at any time on its normal migration route" (see Article I.f of the CMS Convention Text).

Table 2. FRR values for the three management units

Country	Breeding FRR (in km²)	Non-breeding FRR (in km²)	Notes
Russia	112,500	Not provided	Estimates based on the EBBA2 data
MU1 total	***112,500***	***?***	
Denmark	1,800	36,700	FRRs reported by the government
Estonia	1,500	Not provided	Source: Distribution area in national BD Art. 12 report[2]
Finland	19,200	Not provided	Source: Distribution area in national BD Art. 12 report[3]
Norway	n.a.	n.a.	It is not recognised as a naturally occurring breeding species by the government.
Sweden	39,900	Not provided	Source: Distribution area in national BD Art. 12 report[4]
MU2 total	***62,400***	***?***	
Belgium	n.a.	2,100	It is not recognised as a naturally occurring breeding species by the government. The non-breeding FRRs reported by the government
Germany	4,228	Not provided	Source: Distribution area in national BD Art. 12 report[5]
Netherlands	37,621	38,011	FRRs reported by the government
MU3 total	***41,489***	***?***	
Population total	***216,389***	***?***	

Keys: n.a.: not applicable ? : cannot be calculated

Favourable Reference Habitat (FRH)

Assessment of FRH follows the same approach as the habitat for the species in the framework of reporting under Article 17 of the Habitats Directive (DG Environment, 2017, pp. 136-141), i.e. Range States were requested to qualitatively assess whether the extent and quality of the habitat is sufficient for the long-term survival of the population.

Apart from Denmark, no country has reported on the extent and quality of the habitat. However, the FRP is much smaller than the current population size and it can be deduced from this that there is sufficient habitat to support the FRP if there is sufficient habitat to support the current population size.

3. Cumulative impact of derogation and legal hunting

Actions 4.2 of the ISSMP requires to "*asses periodically, and report to the AEWA EGM IWG, the cumulative impact of derogations (as well as hunting in Range States in which derogation is not required) on the development of the population, the likelihood of serious damage to agriculture and risk to air safety and to other flora and fauna (including the Arctic ecosystems), and the non-lethal measures taken to prevent damage/risk, as well as the effectiveness of these. If necessary, coordinate the derogation measures between Range States to avoid risk to the population and to enhance the effectiveness of the measures*".

Consequently, the ISSMP does not define any target size for the population or any of its management units. It remains the sole responsibility of the individual Range States to take or not to take derogation measures in full compliance with the provisions of Articles 9 of the EU Birds Directive and of the Bern Convention.

Based on the above, the role of the Adaptive Flyway Management Programme for Russia/Germany & Netherlands population of the Barnacle Goose is not to maintain the population at a certain target level, but to prevent that the population or any of its MUs decline below the FRP. Thus, the FRPs represent the lower limits of the legally acceptable population sizes but not targets for population reduction. Monitoring of the population size and harvest, predictive modelling of the cumulative impact of national derogation measures and hunting (where it is legally allowed) will be used to inform national decision-making to ensure this.

It follows from this logic that monitoring, assessment and, especially, coordination amongst the Range States is less important when both the population and all of its MUs are well above the FRP. However, these activities become increasingly important when the actual population size is approaching the FRPs either at the population or at the level of any of the MUs. Therefore, a tiered system of coordination is recommended (Table 3). 200% of the FRP of the population or any of its MUs is proposed to trigger the tighter coordination of offtake amongst the Range States[12].

Table 3. Monitoring, assessment and offtake coordination depending on the status of the population

Actual size of the population and its MUs	Measures
> 200% of the FRP	• Monitoring of population size, offtake under derogation and hunting; • Prediction of population development.
< 200% of the FRP	• Monitoring of population size, offtake under derogation and hunting; • Prediction of population development; • Coordination of offtake under derogation and hunting; • Taking coordinated conservation measures, if necessary.

[12] 200% of the FRP has been selected as a threshold to trigger coordination of offtake based on the precautionary principle as, everything else being equal, the closer the population is to the FRP the higher the risk that the population drops below the FRP if derogation and/or hunting is excessive or because of other reasons (such as increased predation). Such an ample buffer is also needed because breeding population estimates in many countries of MUs 2 and 3 are only updated once in every 6 years. Consequently, the population models need to make predicions for longer intervals ahead, which increases their uncertainty. In addition, everything else being equal, the higher the actual population size is compared to the FRP, the more time is available to diagnose the causes of decline and to take conservation actions, if necessary, to maintain the population above the FRP.

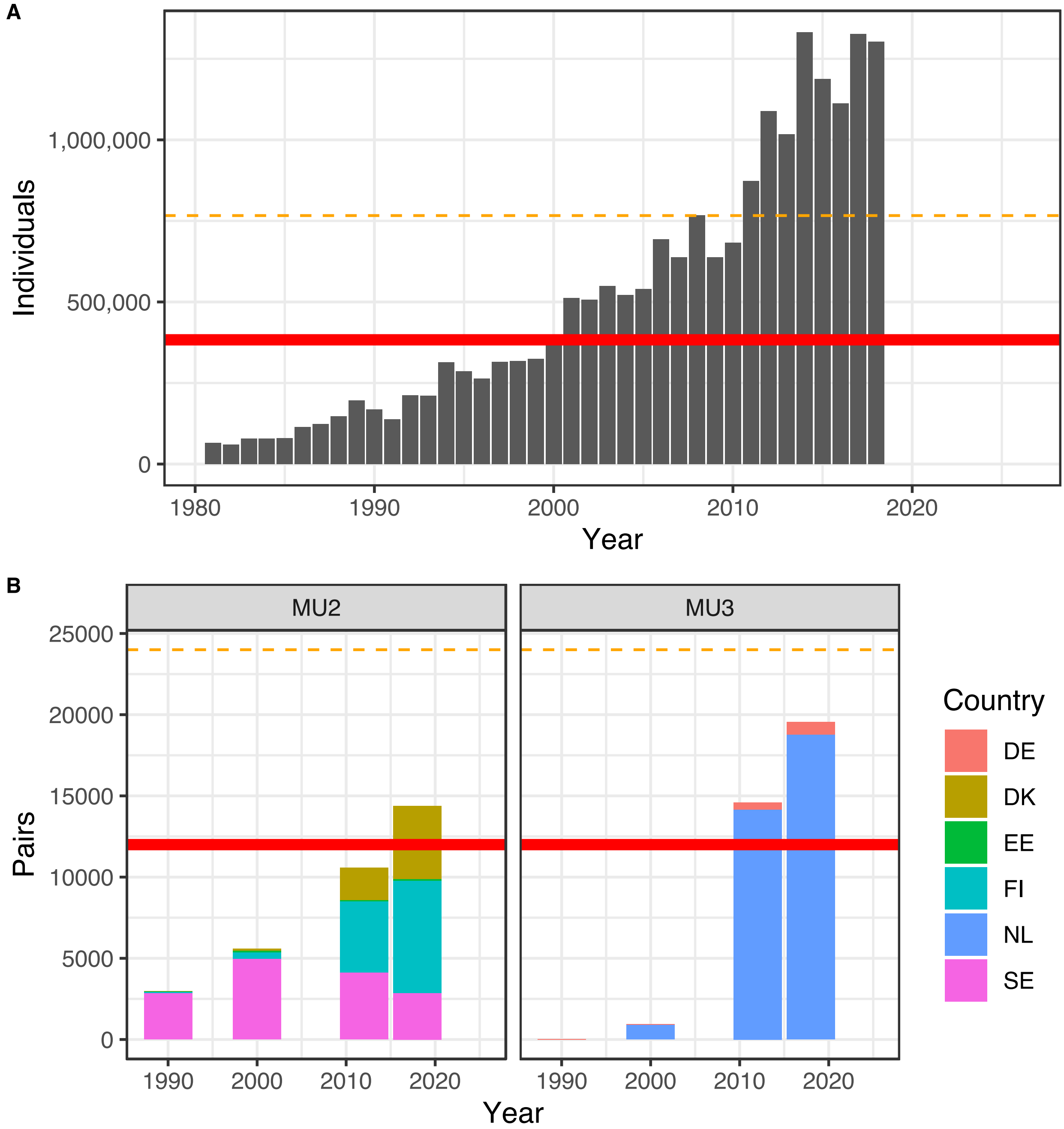

Figure 1. Conceptual representation of the management concept for Barnacle Goose. The bold red line represents the FRP of the population. This marks the minimum size of the population to be considered in FCS. The dashed orange line represents 200% of the FRP. This marks the threshold below which coordinating of offtake amongst Range States should start. (A) The development of the wintering population of the Russia/Germany & Netherlands population based on Koffijberg *et al.* (2020), (B) Development of the breeding populations in MUs2 and MU3. Sources for different time periods in panel (B) are for 1990: Heath *et al.* (2000), for 2000: BirdLife International (2004), for 2012: BirdLife International (2015), for 2018: EU Member States Birds Directive Article 12 reports for the period of 2013 – 2018. (No reliable long-term time series are available for the breeding numbers in MU1).

Currently, the population size is more than 3.5-times larger than the FRP at the level of the whole flyway population.

An Integrated Population Model is being developed for the Russian MU (MU1) by the Dutch working group on Barnacle Goose (Baveco *et al*. 2020 in Annex 3 of this AFMP). This suggests that the population growth might be levelling off at around 1 million bird, but more data is needed for a definitive conclusion. Results also indicate that current reproduction and juvenile survival rates are relatively low due to natural causes and possibly due to the unknown level of offtake in Russia. This implies that there is some risk of population decrease in the near future even with low rates of derogation offtakes. However, the actual population size in this MU is likely to be still more than 4-times larger than the FRP.

However, the actual population sizes at MU level are below 200% of the respective FRPs both in case of MU2[13] and of MU3 (Table 4 and Figure 1). Therefore, it will be necessary to start assessing the cumulative effect of offtake immediately based on (post-)breeding season counts and collection of reliable data on offtake. In MU2, it will be necessary to start coordinating off-take measures in order to avoid that the population size declines below the FRP. Similar coordination of offtake will be not necessary for derogations concerning breeding birds in MU3 because these are sedentary birds, the FRPs are defined at national level and the majority of birds breed in the Netherlands (Figure 1). However, coordination will be necessary concerning derogation measures that might affect birds from MU2.

Table 4. Actual population sizes in relation to the respective FRPs

MU	FRP (in pairs)	Actuals (in pairs)	Actuals / FRP
MU1[14]	105,165	451,215	429%
MU2	12,000	14,500	121%
MU3	12,000	19,563	163%
Population (in individuals)	380,000	1,300,00 – 1,400,000	355%

4. Monitoring indicators and programmes

Monitoring indicators are designed to measure the progress towards the fundamental objectives of the ISSMP (Jensen et al., 2018, pp. 17-18). Indicators are presented in Table 5 for each Fundamental Objective. For each indicator, the rationale, the definition of the indicator and the indicator protocol is presented in Annex 5.

[13] In MU2, this is mainly because most Range States have not reported any FRP and therefore the Current Values (2013-2018) was taken as the FRP value.

[14] The actual number of potential breeding pairs is calculated from the geometric mean of the 1,300,000 – 1,400,000 individuals winter population estimate of Koffijberg *et al.*, (2020), divided by a factor of 2.78 and deducted the sum of the current breeding population estimates the EU Member States reported to the EU Birds Directive Article 12 process.

Table 5. Indicators for fundamental objectives of the ISSMP (Jensen et al., 2018)

Fundamental objective	Related indicators	Deadlines for reporting
I. Maintain the population at a satisfactory level	I.1 Population size compared to the Favourable Reference Population (FRP)	Annually by 30 April (see also Chapter 5)
	I.2 Range extent compared to Favourable Reference Range (FRR)	31 Dec. 2025
II. Minimize agricultural damage and conflicts	II.1 Relative change in damage payments	31 Dec. 2025
III. Minimize the risk to public health and air safety	III.1 Risk of zoonotic influenza transmission to the general public	No national reporting is required
	III.2 Number of bird strikes with aircrafts caused by Barnacle Goose	31 Dec. 2025
	III.3 Number of Barnacle Geese passing over commercial airports	31 Dec. 2025
IV. Minimize the risk to other flora and fauna	IV.1 Area of natural habitat or habitat of threatened species negatively affected by Barnacle Goose	31 Dec. 2025
V. Maximise ecosystem services	V.1 Number of people enjoying watching geese	31 Dec. 2025
VI. Minimise costs of goose management	VI.1 Relative change in cost of goose management	31 Dec. 2025

5. Protocols for the iterative phase

Management evaluation and adaptation of the Russia/Germany & Netherlands population of Barnacle Goose follows four iterative phases running in parallel (Figure 2):

1. A 10/12 year cycle of the ISSMP[15];
2. Two 6-year cycles of the AFMP, and within the AFMP:
3. Two 3-year cycles assessing if the actual size of the population and its MUs are below the 200% threshold and approaching the FRP;
4. 1-year cycles of monitoring and update of work plans.

[15] The lifespan of the ISSMP is 10 years. However, it might be logical for the EGM IWG to recommend to the AEWA MOP to extend it to 12 years to include two 6-year-long AFMPs.

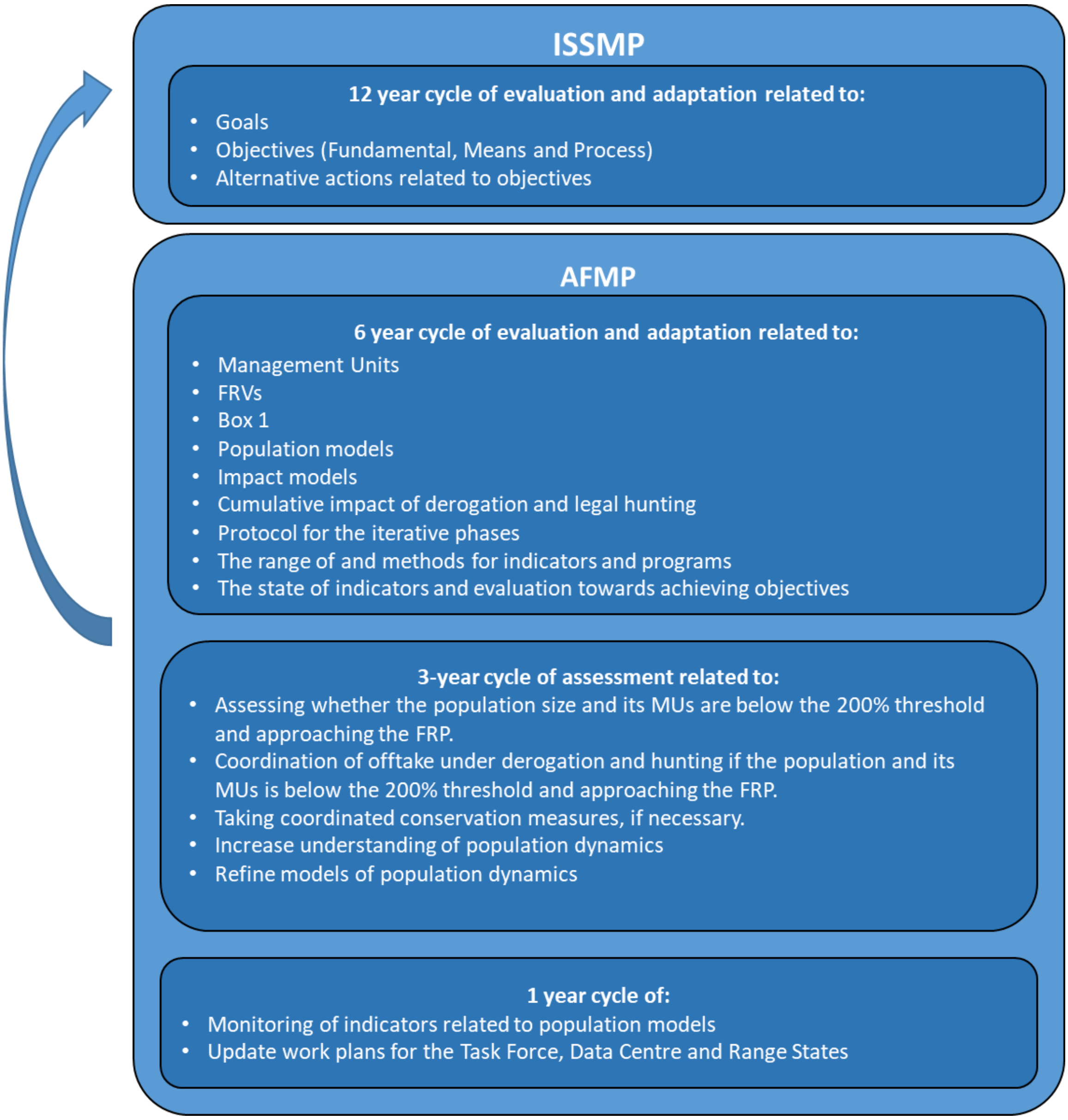

Figure 2. Flow chart of the four iterative phases of the AFMP

10/12 year cycle of the ISSMP

The 10/12 year cycle of the ISSMP encompasses evaluation and adaptation related to

- Goals;
- Fundamental, Means and Process Objectives;
- Alternative actions related to objectives.

6-year cycle of the AFMP

The 6-year cycle of the AFMP encompasses evaluation and adaptation related to:

- Management Units (Chapter 1);
- FRVs (Chapter 2);
- Box 1 (Annex 2);
- Population models (Annex 3);

- Impact models (Annex 4);
- Cumulative impact of derogation and legal hunting (Chapter 3);
- Protocol for the iterative phases (Chapter 5);
- The range of and methods for indicators and programs (Chapter 6, Annex 6);
- The state of indicators and evaluation towards achieving objectives (Chapter 4, Annex 5).

The AFMP is evaluated and adapted next time in 2026 by the EGM IWG.

3-year cycles within the AFMP

The 3-year cycle within the AFMP encompasses assessment related to:

- Assessing whether the population size and its MUs are below the 200% threshold and approaching the FRP;
- Coordination of offtake under derogation and hunting if the population and any of its MUs is below the 200% threshold and approaching the FRP;
- Taking coordinated conservation measures, if necessary;
- Increase understanding of population dynamics;
- Refine models of population dynamics.

1-year cycles within the AFMP

The annual cycle within the AFMP encompasses:

- Monitoring of indicators related to population models;
- Update of work plans for the Task Force, Data Centre and Range States (Annex 1);

Indicators/monitoring related to objectives and population models

To be able to assess whether the population size at MU level is below the 200% threshold and approaching the FRP, a coordinated and systematic monitoring program must be established and maintained. The monitoring program for the long-term data need and the specific activities are listed below (see also IPM report; Annex 3). The activities shall start at the time indicated below in parenthesis and thereafter continued and take place each year.

1. An evaluation of potential bias in reported offtake in each range state (between 2020-2022).
2. Development and implementation of a coordinated and systematic monitoring program including development of detailed monitoring protocols for the long-term data need (between 2020-2022)
3. Monitoring of:
   a. Midwinter counts for each Range State (from January 2021 onwards)
   b. Summer counts per Range States in MU2 and MU3 + proportions of young and older birds (July 2020[16], 2021 and 2024) + development of protocol to convert summer counts to breeding pairs (2020-2022)
   c. Offtake (harvest + derogation) per Range State (from season 2020/21 onwards) and for derogation per month (from season 2022/2023 onwards). Article 9 reportings to the European Commission will be used for EU member state annual totals.
   d. Crippling rate for the same periods as offtake (from season 2020/2021 onwards)

Based on this information, it will be possible to assess whether the population size and its MUs are below the 200% threshold and approaching the FRP at the EGM IWG meeting in 2023.

[16] Only in countries with existing schemes.

Monitoring data is to be submitted to the EGMP Data Centre on an annual basis, and no later than 30 April each year. During the assessment and potential coordination of offtake in 2023 and onwards, up-to-date data have to be available, hence the assessment in 2023, will make use of data up to and including the season 2022/2023. This also means that all existing data up to 2022/2023, which is not already submitted to the Data Centre, should be submitted before the assessment in 2021.

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Annex 1. Population-specific workplans

According to the ISSMP for the Russia/Germany & Netherlands population of Barnacle Goose, the AFMPs set out annual workplans for the ISSMP actions relevant for the population/management unit. At the current stage, due to the limited data available on the population size and offtake, its harvest cannot be managed at MU-level. In addition, most management actions will be overlapping. Therefore, it is proposed to establish one workplan for both management units. As the role of the workplan is to guide the implementation of the ISSMP, the prioritisation and timescale agreed in the ISSMP provides a framework for the work planning process. The ISSMP prioritises actions as Essential, High and Medium priority and assigns time-scales to actions as follows: *Immediate*: launched within the next year, *Short*: launched within the next 3 years, *Medium*: launched within the next 5 years, *Long*: launched within the next >5 years, *Ongoing*: currently being implemented and should continue, *Rolling*: to be implemented perpetually. In essence, this timescale system can be seen as a mechanism to stagger the implementation of actions taking into account both their dependencies and urgencies (Figure 3).

The timescale in combination with the priorities set in the ISSMP can be used to phase the implementation of actions. Thus, the most important would be to implement Essential actions that have an Immediate timing, followed by High priority with Immediate timing, etc.

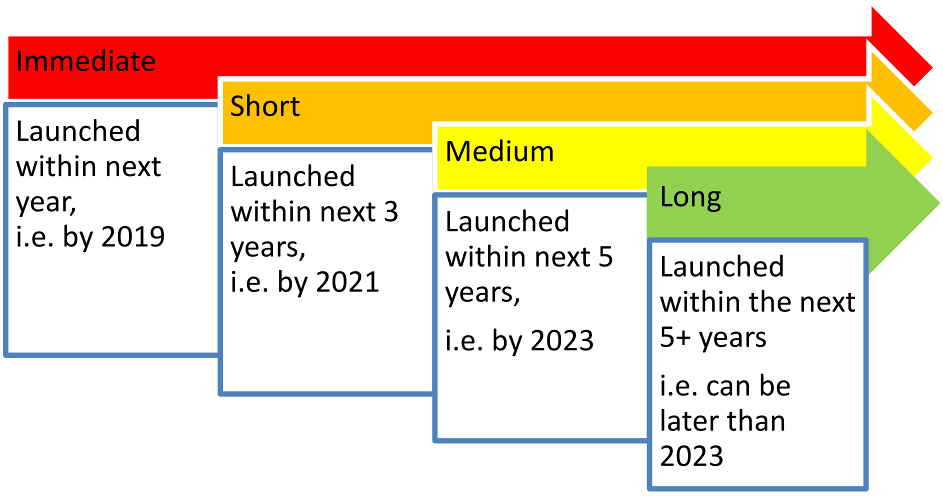

Figure 3. Timescale for the implementation of the ISSMP for the Russia/Germany & Netherlands population of Barnacle Goose.

Implementation of the ISSMP requires work by different entities. Some actions should be done at national level as part of national workplans. To facilitate coordination amongst Range States, it is proposed to establish population-specific Task Forces for the Barnacle Goose (AEWA/EGMIWG/5.23).

On the other hand, there are actions that are cross-cutting, affecting not only the population/management unit for which the work plan is developed but also some populations of other EGMP species such as the Greylag

It is proposed that each EGM IWG entity contributing to the implementation of the ISSMP for the Russia/Germany & Netherlands population of Barnacle Goose uses a common structure to produce its own workplan. This structure includes the ISSMP actions relevant for the time period (i.e. 2020/2021 between the 5th and 6th meeting of the EGM IWG), their priority and timescale as defined in the ISSMP, list of activities to be implemented by the entity (e.g. a Range State, the Russian Barnacle Goose Task Force, Data Centre and the relevant cross-cutting Task Forces). It is recommended that in the period of 2020/2021, the EGM IWG entities focus on implementing the activities that have a timescale of Immediate or Short and focus first on the Essential ones followed by High and then by the Medium priorities as capacity allows.

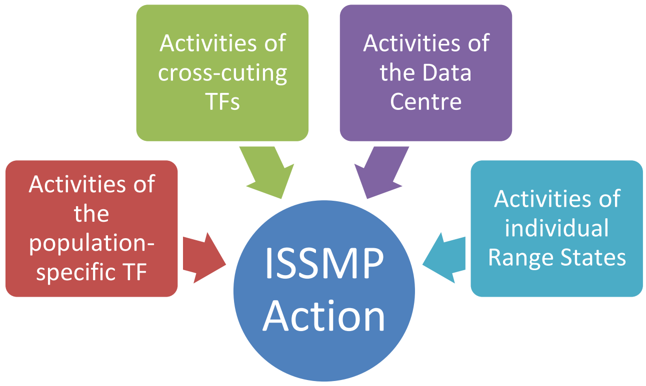

Figure 4. Entities contributing the implementation of the implementation of the Russia/Germany & Netherlands population of Barnacle Goose ISSMP and would need to develop annual workplans.

An online form is available at:
https://docs.google.com/spreadsheets/d/1M64HWxzVagM9W0mG8iMMeVYS3_-M44W6QsHvvUonST8/edit#gid=1472654637

It is proposed that the Data Centre will develop its workplan before the EGM IWG5. The Range States, the Agriculture Task Force and the proposed Russia/Germany & Netherlands Barnacle Goose Task Force will develop their own workplans following the adoption of the AFMP at EGM IWG5, but before 30 September 2020. The workplans of the population-specific TF, the Agriculture TF and the EGMP Data Centre will be adopted by the EGM IWG in writing and revised at the next meeting of the EGM IWG in June 2021 (EGM IWG6).

Annex 2. Box 1 of the ISSMP for the Barnacle Goose

The ISSMP requires the use of a more detailed analysis concerning damage and site protection, as set out in Box 1 of the ISSMPs with the purpose to assist Range States in assessing the need for derogations from the provisions of Articles 5-8 of the EU Birds Directive and in coordinating the implementation of their derogation schemes. Each AFMP should therefore contain information that is relevant for assessing the need for derogations at Range State level.

A two-year project (2019-2021) is funded by the German Federal Ministry for the Environment and Nuclear Safety (BMU) and coordinated by the EGMP Data Centre. The project started in December 2019 and is expected to end in July 2021 with results ready for the 6th Meeting of the EGM IWG (EGM IWG6 in June 2021). In December 2019, a questionnaire for each species was sent to the Range States. The deadline for responses was set by 31 January 2020 and later postponed to 31 March 2020. Responses have been received from most countries (Table 1). However, the degree of information from the countries varies from very little information to almost full response to all questions. A questionnaire regarding air safety is treated separately by direct contact to the relevant national air safety organisations. The EGMP Agriculture Task Force will be consulted for matters regarding agricultural damage. All data will be synthesized and used for the final report at the end of the project period in 2021.

Table 1. All countries requested for data in relation to Box 1. Responses received by the deadline 31 March 2020 are indicated by an X.

Country	Barnacle Goose
Belgium	X
Denmark	X
Estonia	
Finland	X
Germany	
Latvia	X
Netherlands	X
Norway	X
Sweden	X

Annex 3. Population Models

DEVELOPMENT OF AN INTEGRATED POPULATION MODEL FOR BARNACLE GEESE OF THE RUSSIAN MANAGEMENT UNIT

Progress Report prepared by the Dutch working group on Barnacle Goose in collaboration with the EGMP Data Centre

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Summary

An Integrated Population Model was developed for the Russian Barnacle Goose population of the Russia/Germany & Netherlands flyway, with the aims 1) to assess current demographic rates in particular productivity and survival rates (from natural causes and unknown offtake in Russia), 2) to reconstruct the dynamics and assess the current state (size) of the Russian management unit (MU1), correcting for the increasing presence of birds from newly established Baltic and North Sea management units (MU2 and MU3), 3) to assess the offtake rate imposed upon the Russian MU and the other two MUs from derogation shooting in recent years in the Baltic Sea and North Sea regions. The IPM used counts of the total flyway population, observed juvenile proportions, reported derogation killing, and reconstructed summer counts of the Baltic and North Sea MUs. The results from the IPM analysis were used in scenarios of future population dynamics under different derogation offtake rates.

The results suggest that the Russian MU population might be levelling off at around 1 million birds. The stabilization appears only in the IPM results for the recent few years, and more data will be needed to arrive at a definite conclusion. Results also indicate that current reproduction and juvenile survival, due to natural causes and unknown Russian offtake, are relatively low. This implies that even with low derogation offtake rates there is some risk of population decrease in the near future.

As systematic bias in reported offtake cannot be excluded, further exploration of the consequences of under- and overreporting on the estimated demographic rates and future population perspectives at MU levels is needed.

1. Introduction

In the Flyway Management Plans for Barnacle Goose and other goose species, which are currently being implemented by the European Goose Management International Working Group (EGM IWG), dynamic population models play an important role in the guidance of optimal management strategies. To be able to apply such models, e.g., in scenario studies with different levels of derogation shooting with the aim of reducing agricultural damage, the current demographic rates of the population need to be known. When monitoring data are scarce or data from different sources need to be combined, an Integrated Population Model (IPM) approach allows one to estimate demographic rates analysing all available data in an integrated way.

The Barnacle Geese of the Russia/Germany & Netherlands flyway belong to either the original and by far largest migratory population breeding in arctic Russia or to one of the new populations established in the past decades in the Baltic and North Sea regions. These populations may have quite different demographic rates. In particular, the survival rates of the Russian population may differ as it experiences (unknown) offtake in Russia in addition to (reported) derogation offtake in the EU. The population may also have lower productivity compared to the recently established populations (Van Der Jeugd et al. 2009, van der Jeugd and Kwak 2017).

Given these possible differences in demographic rates, the development of an IPM treating the entire flyway population as a single entity and assessing the 'average' demographic rates, does not seem a good idea, because differences in rates will change the proportional contribution of the different subpopulations to the total population. Scenarios based on the average rates can then be misleading.

Monitoring data for the Russia/Germany & Netherlands flyway concern the total flyway population (January counts) or (combinations of) specific subpopulations (Koffijberg et al. 2020). In this study an IPM is presented that allows to assess the demographic rates specifically for the Russian population, taking into account the presence of birds from the Baltic Sea and North Sea populations in the collected monitoring data sets.

This progress report presents work in progress. It will undergo a thorough scientific peer review in the near future.

1.1 Management units

At the 4th meeting of the AEWA European Goose Management International Working Group (EGM IWG), 18-20 June 2019 in Perth (Scotland, UK), it was proposed to divide the management of the Russia/Germany & Netherlands population into three administratively defined Management Units (MUs) (EGMP 2019). The proposed MUs, all wintering in the same range in the Netherlands, Belgium, Germany, Denmark and south Sweden, are:

- MU1: The arctic Russian breeding population (migratory).
- MU2: The temperate Baltic breeding population, including the Oslo Fjord breeding population (migratory).
- MU3: The temperate North Sea breeding population, breeding in the Netherlands, Belgium, Germany and south-west Denmark (considered sedentary).

This study focusses on MU1, the population breeding in arctic Russian, as the by far largest one, with migratory behaviour that is considered to be of high conservation value. Following an increase in the size of the total flyway population in the wintering areas, derogation killing, aiming at a reduction of agricultural damage, recently increased in several of the range states. All MU populations are affected by derogation offtake, and for each population there will be a certain point where increased offtake rates balance productivity, and population size will stabilize or start to decrease. The migratory MU1 population could be more vulnerable due to additional constraints, e.g., in the breeding period, compared to MU2 and especially MU3 (Van Der Jeugd et al. 2009, van der Jeugd and Kwak 2017).

Due to the migratory behaviour of MU1 birds, their presence spatially overlaps for part of the year with that of birds from the Baltic and North Sea management units. Monitoring data may thus refer to the total flyway population or to specific management units. In the approach taken here we use data specific for the Russian population where possible, and where these are not available we explicitly take into account the presence of birds from Baltic and North Sea MUs.

1.2 Integrated population modelling

For the Barnacle Geese of the Russia/Germany & Netherlands population there are several sources of monitoring data (Koffijberg et al. 2020). IPMs incorporate all these data into a single analysis (Schaub and Abadi 2011, Kéry and Schaub 2012) to obtain estimates of demographic rates and population sizes. Besides the ability to ‘reconcile’ all data, additional advantages of IPMs include the proper propagation of uncertainty, the ability to handle missing data and to estimate latent variables, and applicability of the approach in an adaptive framework (Johnson et al. 2020). IPMs assume the absence of systematic bias in monitoring data. If such bias exists, it can sometimes be investigated and corrected for in the analysis (Saunders et al. 2019, Johnson et al. 2020).

The aim of the IPM developed for MU1 is threefold:

- Estimating the demographic rates for the Russian MU, in particular the productivity and the survival rates, which incorporate both natural survival and unknown offtake in Russia but exclude derogation in the other range states.
- Reconstructing the dynamics and assessing the current state (size) of the Russian population (MU1), correcting for the increasing presence of birds from newly established Baltic and North Sea populations (MU2 and MU3, respectively).
- Assessing the offtake rate imposed upon the Russian population and the other two populations by derogation shooting in recent years in the Baltic Sea and North Sea regions.

The results obtained from the IPM analysis provide the base for projections of future population development and an impact assessment of derogation efforts.

1.3 Baltic and North Sea MU

As a next step in the modelling of the Russia/Germany & Netherlands flyway models will be developed for the Baltic and North Sea MUs, using the insights obtained from the IPM analysis for MU1 and benefiting in particular from the disentanglement of monitoring data with respect to the management units they relate to. It is not clear yet whether for MU2 and MU3 sufficient data will be available (Koffijberg et al. 2020) to allow for the development of useful IPMs. If not, population dynamic models can be constructed based on the more traditional approaches to estimate the individual demographic rates (separately instead of integrated), e.g. as in (Huysentruyt et al. 2020).

2. Monitoring data

Monitoring data were obtained from (Koffijberg et al. 2020). Further data processing and analysis outside the IPM, e.g. to extract subsets of data relevant to the Russian population, is described in the following sections.

The IPM developed in the next chapter is based on a post-breeding census at 15 July. A yearly time step then runs from 15 July to 15 July the next year, and will be called a season which is denoted by e.g., 1990/91. The January count of the population occurs halfway the annual time step. Therefore each yearly time step is split into two half-year periods called period *s* or “summer” (15 July to 15 January) and period *w* or “winter” (15 January to 15 July). This enables specification of different survival and offtake rates in the two periods, but requires that e.g. annually reported derogation offtake is divided over the same periods.

2.1 Population counts

Mid-January counts refer to the total flyway population, the sum of MU1, MU2 and MU3.

In the counts no distinction is made between juveniles and adults. The first count was performed in 1976 in the season 1975/76, while the last count used here is for January 2018, i.e. the season 2017/18. Counts are organised per country. For Germany counts are missing for the first five and the last two seasons. The first five counts in Germany are set to zero since the first available counts in Germany are very low as compared to the total numbers in all other countries (in particular, The Netherlands). For imputation of the last two counts in Germany, which will become available in due time, logistic regression was used to obtain a provisional estimate. The number of counts in Germany was therefore assumed to follow a quasi-binomial distribution with binomial denominator the total population count, and a probability π that a single goose resides in Germany. A smoothing spline with 4 degrees of freedom in Year was fitted to these data. This reveals that from the season 1999/00 onwards the percentage in Germany is more or less constant albeit with considerable variation. This constant percentage was confirmed by a non-significant linear term in time from 1999/00 onwards and also from 2004/05 onwards. It was therefore decided to impute the last two observations in Germany using a constant logistic model from 2004/05 onwards. The estimated constant percentage equals 25.5. The resulting imputed counts are 338,624 and 332,443 for January 2017 and 2018, respectively.

2.2 Survival

Preliminary estimates of total survival, incorporating the impact of derogation offtake in NW Europe and unknown harvest in Russia, are available specifically for MU1.

De Vries and Van der Jeugd (personal communication) provided preliminary survival rates, obtained from analysis of capture-mark-resighting data submitted to the geese.org portal, for the three different MUs of Barnacle Goose, based on a combination of observations of colour-ringed individuals taken from the geese.org database, and recoveries of metal-ringed individuals provided by EURING. There are separate survival rates for juveniles and adults, period *s* and *w*, and also for the periods before and after 15 July 2007, when derogation shooting increased markedly. The estimated rates and associated confidence intervals for the Russian population are given in Table 1. These rates include offtake, both in Russia and in NW Europe. Note that (1) the rates are generally very precise with small confidence intervals especially for adults, (2) the juvenile summer survival rates are lower than the other rates, and (3) the survival rates after 2007 are lower than before 2007 which might reflect the onset of derogation shooting of Barnacle geese in the Baltic and North Sea regions after 2007.

Table 1: Estimated total survival rates, including offtake, for the MU1 population categorized by stage, summer/winter and observation period. The standard error (Se) of the estimate and a 95% confidence interval (CI) are given.

Stage	Summer/Winter	Period	Estimate	Se	CI left	CI right
Juvenile	Summer	Before 2007, 15 July	0.7438	0.0224	0.6976	0.7852
Juvenile	Winter	Before 2007, 15 July	0.9662	0.0190	0.9012	0.9889
Adult	Summer	Before 2007, 15 July	0.9687	0.0067	0.9526	0.9794
Adult	Winter	Before 2007, 15 July	0.9751	0.0071	0.9566	0.9858
Juvenile	Summer	After 2007, 15 July	0.4871	0.0305	0.4277	0.5468
Juvenile	Winter	After 2007, 15 July	0.8785	0.0405	0.7746	0.9383
Adult	Summer	After 2007, 15 July	0.8906	0.0121	0.8646	0.9122
Adult	Winter	After 2007, 15 July	0.9244	0.0141	0.8917	0.9478

2.3 Derogation offtake

Derogation offtake is reported to the EU annually and per country. Derogation may concern birds from MU1, MU2 and/or MU3. A subset of the data was constructed, excluding the derogation offtake that could not concern MU1 birds. For The Netherlands, this subset was based on more detailed, monthly data.

The Barnacle Goose is listed as Annex 1 species in the EU Bird Directive. Offtake by derogation in EU countries therefore has to be reported annually to the EU. Data from the EU and national level (Koffijberg et al. 2020) are processed to obtain the derogation offtake per half year periods *s* and *w* for the Baltic Sea and North Sea regions. No distinction could be made between juveniles and adults.

EU Derogation data were derived from the assessment made for the ISSMP (Jensen et al. 2018), in which national data were assigned to the management units (either all three management units, or a selection, based on the timing of derogation shooting). We divided them over the period *w* (Jan 15 - Jul 15) and period *s* (Jul 15 - Jan 15) in proportion 3:1, thus assuming that three times as many birds were killed in the first half of the year (when most agricultural damage occurs) as in the second half. Note that the two periods of one calendar year end up in different timesteps of the IPM. Relevant annual data were available from Denmark, Germany and The Netherlands, but missing for Estonia. Available data from Belgium and Sweden mainly (or entirely) covered the local breeding population and were not taken into account.

For The Netherlands from 2013 onwards detailed monthly data were employed. For the Dutch subset of relevant derogation data, the months June, July, August and September were removed as these referred to resident birds (MU3) only. For the remaining months values for all provinces were summed. Values summed over the months February to May represented derogation offtake in period *w*, while values summed over the months October to December yield derogation offtake in period *s*. Data for January were divided equally over the two periods, to align with the model timestep.

The derogation subset for The Netherlands represented the North Sea region offtake. Values for Denmark represented derogation offtake in the Baltic Sea region. Values for Germany (up to almost 2000 birds) should be added to the North Sea region offtake, and values for Sweden and Norway (also around 2000) should be added to the Baltic Sea region offtake - not all derogation data were however available at the time of this analysis. Thus, derogation in recent years in both the Baltic and the North Sea region may be up to approximately 2000 birds per calendar year higher than the numbers used in the analysis (Figure 1).

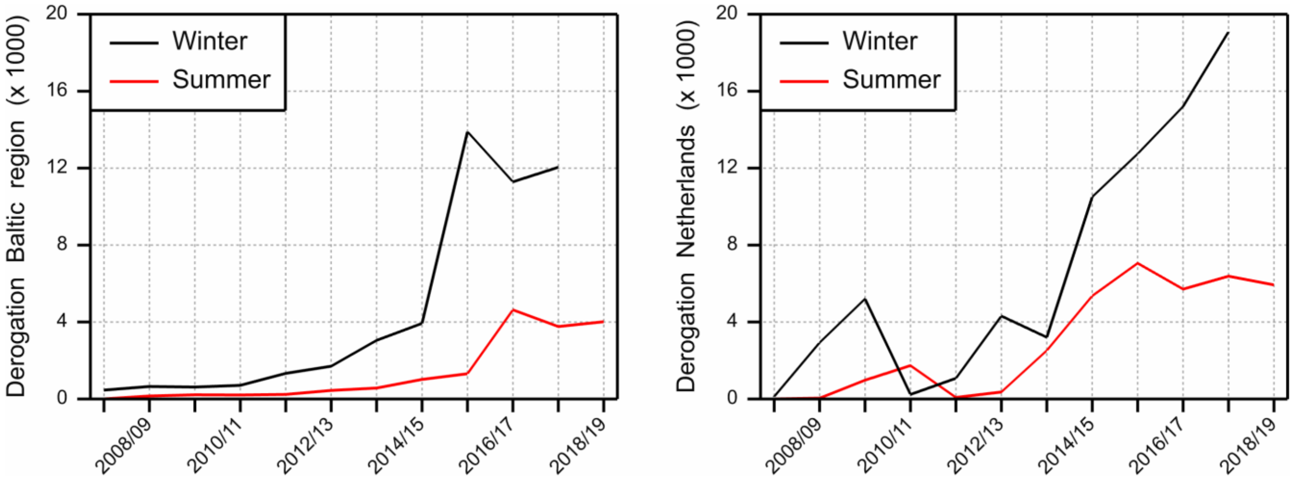

Figure 1: Derogation offtake in period *s* and *w* in Baltic Sea region (left), where it affects MU1 and MU2, and in the North Sea region (right), where it affects MU1, MU2 and MU3.

2.4 Proportion of young

Data on the proportion of juveniles were available for The Netherlands, since 1996/97. A selection of the data was made including provinces with migratory birds (MU1 and MU2) and no wintering resident birds (MU3). The data contain thus information on the productivity of MU1 and MU2 together (Koffijberg et al. 2020). With MU2 being less than 10% in size of MU1, we assumed that the observed proportions represent yearly productivity of MU1.

The number of juveniles in groups of Barnacle Geese have been counted on a total of 1153 occasions in September – March for the seasons from 1996/97 and onwards. Very few groups were observed in September, February and March and data for these months were therefore excluded. The juvenile counts have been carried out in de wintering areas where mainly Russian and Baltic birds winter, see (Koffijberg et al. 2020) for details. Observed percentages per season are sometimes very variable and the percentage juveniles seems to decrease somewhat over time (Figure 2). The mean percentages per month from October to January appear to be more or less stable (Figure 3); it is therefore assumed that the percentage juveniles is constant within a season (at least for the period October-January).

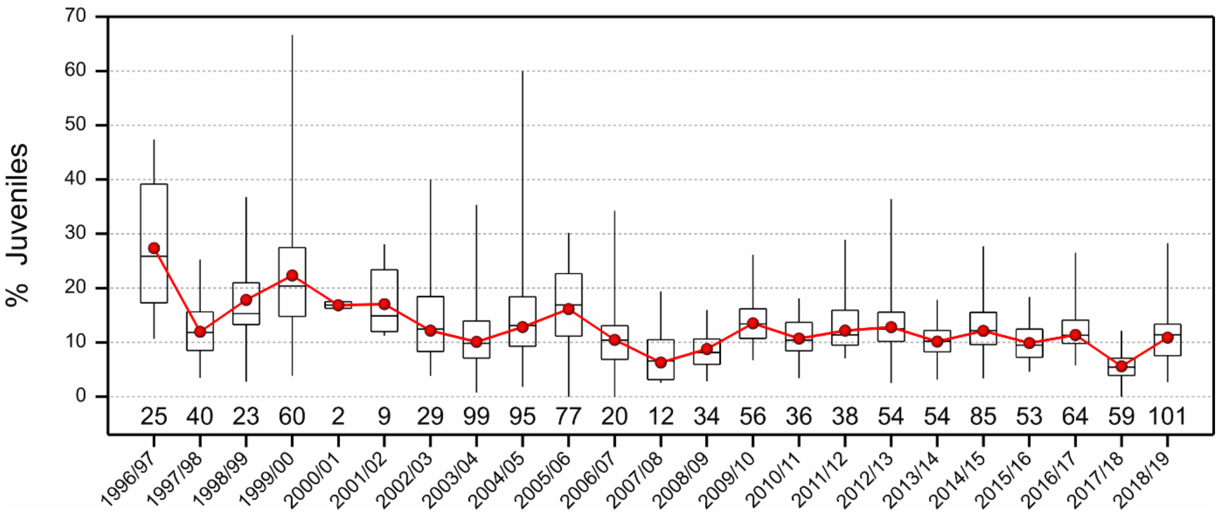

Figure 2: Boxplot for observed percentages juveniles for each season (October – January); the red line joins the mean percentages that were weighted by the group size. The count just above the x-axis gives the number of counted groups per season.

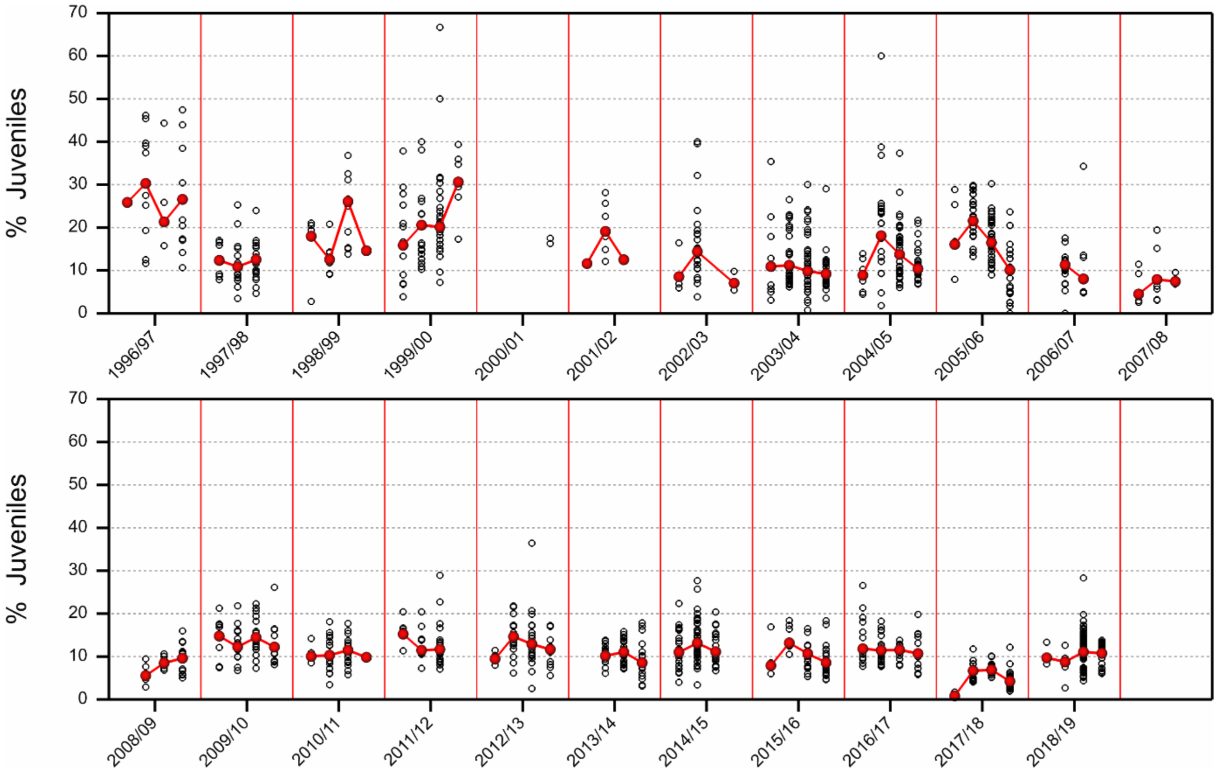

Figure 3: Observed percentage juveniles per season and within season for October, November, December and January (from left to right within season). The red line joins the weighted means of the percentages within each season.

The counts within a season are for different groups and are therefore considered to be independent. The counts of juveniles and group sizes are therefore summed per season.

The juvenile and group counts discussed so far are for the season 1996/97 and onwards. Before that only raw juvenile percentages are available, with missing values for the seasons 1991/92, 1992/93, 1994/05 and 1995/96. Moreover, for the period 1980/1981 – 1993/94 total group sizes are also available. This implies that only for the seasons 1975/76 – 1979/80 group sizes are missing. For these years the total group size was (arbitrarily) set to the mean of the first 6 years in the period 1980/1981 – 1993/94. Figure 4 displays the resulting total group sizes per season.

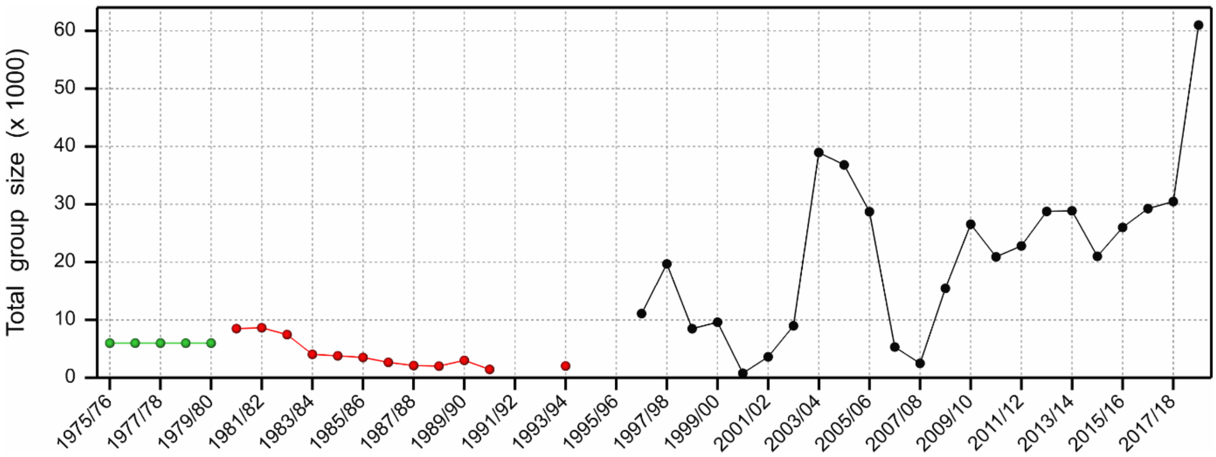

Figure 4: Total group sizes per season in which the percentage juveniles was determined. The black dots denote years for which the total group size is summed over many individual groups, the red dots denote years for which only total group sizes are available, and the green dots denote the years for which the total group size was set to the mean of the first 6 red dots.

A simple logistic regression on the individual counts for the season 1996/97 and onwards with a factor season resulted in a mean residual deviance of 8.4 indicating that there is quite some overdispersion within seasons relative to the binomial distribution. A beta-binomial distribution for the number of juveniles in a given group size is therefore appropriate. To quantify the amount of overdispersion per season the approach of Johnson et al. (2020) was followed. This amounts to first taking the mean and variance of the observed proportions of Juveniles within each season. The year specific means M_t and variances V_t were then used to fit year-specific beta distributions, Beta(α_t, β_t), for the proportion of Juveniles employing the method of moments, i.e. $\alpha_t = \omega_t M_t, \beta_t = \omega_t (1 - M_t)$ with $\omega_t = M_t(1 - M_t)/V_t - 1$. Note that $\omega_t = \alpha_t + \beta_t$. The estimates are given in Table 2. The estimated yearly parameters of the Beta distribution can then be used to obtain a 95% interval for the proportion of Juveniles as in Figure 5. This again reveals that there is quite some variation in the observed proportions juveniles per season. The interval for 2000/01 is small; this interval is only based on two observed groups.

Table 2: Number of observed groups, means and standard deviations of observed proportions Juveniles, estimates of parameters α, β and $\omega = \alpha + \beta$ of the Beta distribution, and lower and upper limits of a 95% interval for the proportion Juveniles based on the fitted Beta distribution.

Season	#Groups	Mean	Sd	α	β	ω=α+β	Lower	Upper
1996/97	25	0.280	0.123	3.47	8.94	12.40	0.079	0.547
1997/98	40	0.122	0.049	5.40	38.89	44.29	0.044	0.232
1998/99	23	0.181	0.081	3.91	17.66	21.57	0.053	0.365
1999/00	60	0.220	0.112	2.83	9.99	12.82	0.049	0.474
2000/01	2	0.169	0.009	312.01	1535.95	1847.96	0.152	0.186
2001/02	9	0.174	0.065	5.71	27.09	32.80	0.067	0.319
2002/03	29	0.150	0.092	2.09	11.83	13.92	0.022	0.371
2003/04	99	0.116	0.066	2.67	20.25	22.91	0.023	0.272
2004/05	95	0.151	0.086	2.46	13.84	16.30	0.027	0.354
2005/06	77	0.167	0.076	3.83	19.06	22.89	0.048	0.341
2006/07	20	0.111	0.069	2.16	17.30	19.45	0.016	0.279
2007/08	12	0.079	0.053	1.99	23.04	25.03	0.010	0.210
2008/09	34	0.085	0.029	8.10	86.69	94.79	0.038	0.149
2009/10	56	0.138	0.043	8.77	54.86	63.63	0.065	0.232
2010/11	36	0.109	0.036	7.89	64.63	72.52	0.049	0.189
2011/12	38	0.130	0.047	6.70	44.71	51.41	0.054	0.234
2012/13	54	0.132	0.054	5.10	33.37	38.46	0.046	0.255
2013/14	54	0.103	0.033	8.69	75.80	84.48	0.048	0.175
2014/15	85	0.127	0.046	6.46	44.46	50.93	0.051	0.230
2015/16	53	0.101	0.037	6.49	57.65	64.13	0.041	0.185
2016/17	64	0.121	0.038	8.76	63.72	72.49	0.057	0.205
2017/18	59	0.056	0.025	4.85	81.33	86.18	0.018	0.113
2018/19	101	0.111	0.039	7.05	56.47	63.53	0.047	0.198

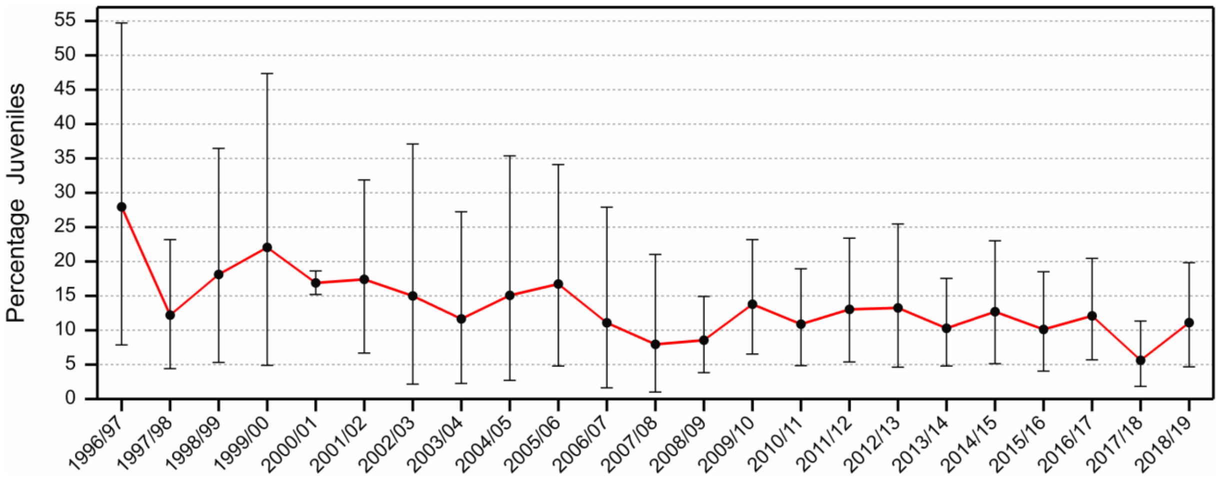

Figure 5: Mean percentages juveniles per season, un-weighted by group size, with 95% intervals according to a Beta distribution obtained by applying the method of moments per season.

2.5 Summer counts for the Baltic and North Sea management units

To account in the IPM analysis for the presence of birds from the Baltic and North Sea management units, estimates of the size of the Baltic and North Sea population are required. Data compiled in (Koffijberg et al. 2020) were used to obtain (rough) estimates of MU2 and MU3.

The North Sea MU consist of birds breeding in the Netherlands, Germany and Belgium. The latter two were ignored, because of their relatively small size. For the Dutch population post-breeding summer counts are available from 2005 onwards. The missing data in this time series were linearly interpolated. For the period before 2005 exponential growth was assumed with a high annual growth rate of 46% (Van der Jeugd et al. 2006). The first breeding pair was observed in 1982, therefore for this year the summer count was set at four birds (Figure 6).

The Baltic MU consists of breeding populations in mainly Finland, Denmark and Sweden, i.e. small populations in Estonia, Russia and Norway (Oslo fjord) have not been taken into account. Only for the Finnish population, a longer time series of summer counts is available, starting in 2008. For the preceding years, the same 46% growth rate was assumed as for the Dutch population (Figure 6). Fragmentary data on the breeding populations of Denmark and Sweden suggest that these are roughly of the same size as the Finnish breeding population. Therefore, as a first approximation of the total Baltic summer population size, the Finish numbers are multiplied by a factor 3.

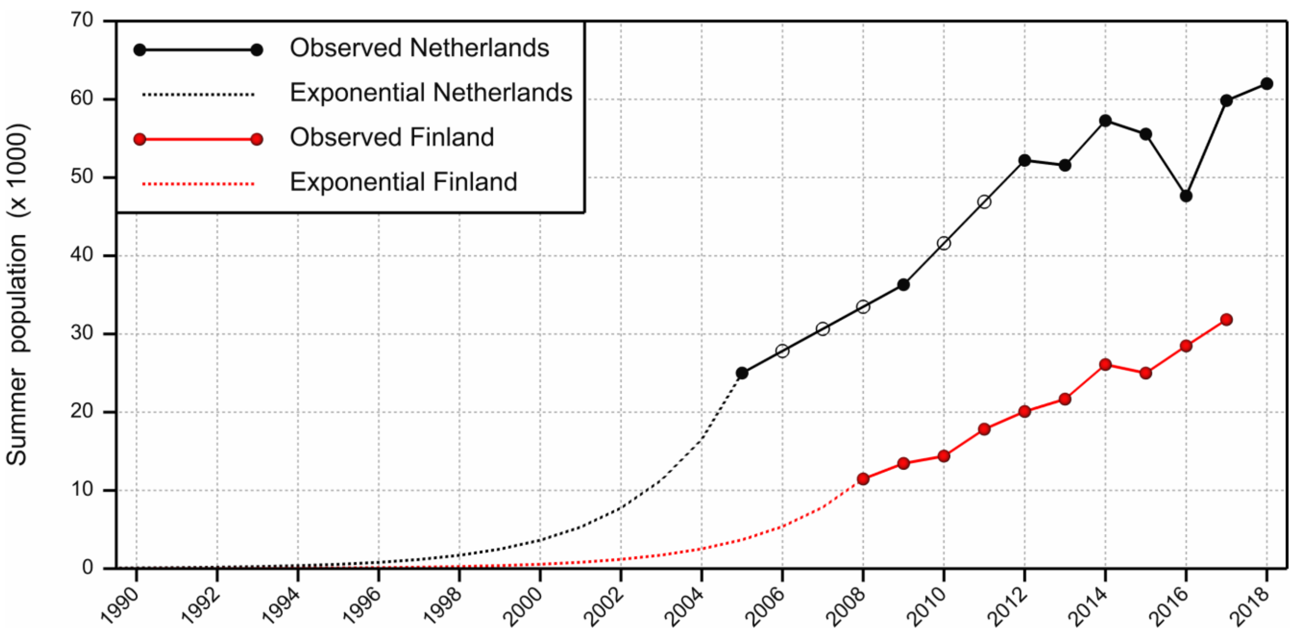

Figure 6: Summer counts for The Netherlands and Finland. Initial exponential growth of the populations is assumed, with 46% annual increase. Open dots are linearly interpolated values.

2.6 Implications for future monitoring

Application of the IPM in adaptive management requires the availability of reliable and complete monitoring data. The data for the developed IPM for the Russian Barnacle Goose population include winter population counts for the total flyway population, juvenile counts specific for the Russian population, derogation data for the periods Russian birds are present in the Baltic and North Sea regions, and summer counts for the Baltic and North Sea populations (Table 3). While developing the IPM and preparing the data the model requires, it became clear that

- January counts and data on juvenile proportions were available in sufficient detail - they should continue to be collected in more or less the same way. Care should be taken that juvenile proportions are determined in groups with predominantly birds of MU1.
- Derogation offtake data were not available in sufficient (temporal) resolution. To assign them to appropriate timesteps in the model, and to be able to select offtake occurring in the period the Russian population is present, the number of birds killed under derogation per country needs to be available over shorter time intervals, preferably per month.
- Summer counts were only available for a limited number of years, and not for all Baltic and North Sea states with breeding populations. For the current application, a rough assessment was made of total population size (in summer) of the Baltic and North Sea MUs. For future applications systematic summer counts are required – such data would also support the development of population dynamic models for the Baltic and North Sea MUs themselves, or a simultaneous IPM analysis for all three MUs (Table 3). Summer counts and juvenile counts may be combined.

Table 3. The monitoring data in terms of the management units, as required for the IPM, and additional data that will be required for future models for MU2 and MU3 (last column). [1]regional derogation offtake in the months (and areas, e.g., provinces) MU1 is present in the region (BS: Baltic Sea region; NS: North Sea region). It depends on the regions which of the other MUs can be present at the same time as MU1. [2]all offtake in the months (and areas) MU1 is absent and only the local breeding population is present in the region.

Monitoring data	Current IPM (MU1)	models (MU2 and MU3)
January counts	All (total flyway population)	
Proportion of young	MU1	MU2 and MU3
Derogation offtake Baltic region	BS[1] (MU1 and MU2)	MU2[2] (=total in BS minus BS[1])
Derogation offtake North Sea region	NS[1] (MU1, MU2 and MU3)	MU3[2] (=total in NS minus NS[1])
Summer counts (post-breeding)	MU2 and MU3	

3. Population dynamics

The population dynamic model assumes two stage classes, juveniles *F* (fledglings at the start of the timestep) and adults *A*, and does not distinguish between females and males. Model definition is based on a post-breeding census in July (Figure 7). Lack of data – in the counts no distinction can be made between sub-adults and adults - motivates the choice for a two-stage model instead of a three-stage model as e.g., described in (Layton-Matthews et al. 2019). Although the IPM can in principle be used to obtain a estimates of sub-adults numbers, as a latent variable, this likely does not justify the added complexity of the model.

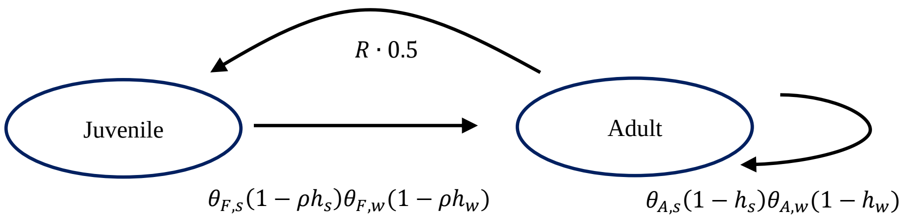

Figure 7: The stage-structured life cycle as represented in the IPM. Juveniles are in the implementation also referred to as Fledglings (F). See text for a definition of the symbols.

The January counts occur halfway the annual time step and we therefore distinguish between survival and harvest rates in the two half-year periods *s* and *w*. Period *s* (July 15 to January 15) and period *w* (January 15 to July 15), occasionally referred to as "summer" and "winter".

The population model deals with the dynamics of the Russian population (MU1) only. To link the model to the monitoring data, the presence of birds of the other MUs needs to be taken into account. We untangle this overlap in management units by using the January counts for the flyway population as a whole and by assuming that for the derogation offtake (the way we defined it, see section 2.3) the offtake in the Baltic Sea region concerns MU1 and MU2, while in the North Sea region it concerns all three Mus. Derogation offtake *rates* then refer to offtake as a fraction of the total population present in the region. Based on (post-breeding) summer counts of MU2 and MU3 as additional monitoring data (section 2.5), estimates of the total flyway population size and derogation offtake rates can be obtained that take into account the overlap in MUs (see below). The summer counts of MU2 and MU3 are used as deterministic values without error because this simplifies the model considerably.

The population model employs the following symbols:

t	timestep, from July 15 to July 15 the next year
s	period *s* (*"summer"*) (July 15 to January 15)
w	period *w* (*"winter"*) (January 15 to July 15)
F	juvenile stage
A	adult stage
$\mathrm{F_t}$	number of juveniles (fledglings) at the beginning of timestep t
$\mathrm{A_t}$	number of adults at the beginning of timestep t
$\mathrm{R_t}$	reproduction rate (fledglings/adult pair) at t ($0.5\ \mathrm{R_t}$ = fledglings / adult)
$\theta_{\mathrm{F,s,t}}$	natural survival (including unknown Russian harvest) of juveniles over period *s* in timestep t
$\theta_{\mathrm{F,w,t}}$	natural survival (including unknown Russian harvest) of juveniles over period *w* in timestep t
$\theta_{\mathrm{A,s,t}}$	natural survival (including unknown Russian harvest) of adults over period *s* in timestep t
$\theta_{\mathrm{A,w,t}}$	natural survival (including unknown Russian harvest) of adults over period *w* in timestep t
$\mathrm{h^B_{s,t}}$	derogation offtake rate in Baltic Sea region, in period *s*, in timestep t
$\mathrm{h^N_{s,t}}$	derogation offtake rate in North Sea region, in period *s*, in timestep t
$\mathrm{h^B_{w,t}}$	derogation offtake rate in Baltic Sea region, in period *w*, in timestep t
$\mathrm{h^N_{w,t}}$	derogation offtake rate in North Sea region, in period *w*, in timestep t
$\mathrm{H^B_{s,t}}$	derogation offtake in Baltic Sea region, in period *s*, in timestep t
$\mathrm{H^N_{s,t}}$	derogation offtake in North Sea region, in period *s*, in timestep t
$\mathrm{H^B_{w,t}}$	derogation offtake in Baltic Sea region, in period *w*, in timestep t
$\mathrm{H^N_{w,t}}$	derogation offtake in North Sea region, in period *w*, in timestep t
ρ	relative sensitivity to derogation offtake of juveniles compared to adults

The correction for the presence of birds from Baltic and North Sea management units requires an additional fixed survival rate θ and two timeseries:

θ	(deterministic) natural survival over period *s* for birds of the Baltic & North Sea MUs
$\mathrm{N^B_t}$	(deterministic) number of birds of the Baltic Sea MU in summer count, in timestep *t*

N_t^N (deterministic) number of birds of the North Sea in summer count, in timestep *t*

The total survival is defined as the product of natural survival (including unknown Russian harvest) and the fraction of birds not killed by derogation, taking into account the relative sensitivity ρ to derogation offtake of juveniles compared to adults:

$\lambda_{F,s,t} = \left(1 - \rho(h_{s,t}^B + h_{s,t}^N)\right) \theta_{F,s,t}$ total survival of juveniles in period *s* in timestep t

$\lambda_{F,w,t} = \left(1 - \rho(h_{w,t}^B + h_{w,t}^N)\right) \theta_{F,w,t}$ total survival of juveniles in period *w* in timestep t

$\lambda_{A,s,t} = \left(1 - (h_{s,t}^B + h_{s,t}^N)\right) \theta_{A,s,t}$ total survival of adults in period *s* in timestep t

$\lambda_{A,w,t} = \left(1 - (h_{w,t}^B + h_{w,t}^N)\right) \theta_{A,w,t}$ total survival of adults in period *w* in timestep t

Note that with this formulation derogation offtake occurs simultaneously in both regions, which is equivalent to assuming that the birds of the Russian management unit are, in the period derogation offtake occurs, evenly distributed over the whole Baltic and North Sea area.

The population dynamics of MU1 is, for a single timestep from *t* to (t+1), defined by:

$$\begin{cases} A_{t+1} = \lambda_{A,s,t}\,\lambda_{A,w,t}\,A_t + \lambda_{F,s,t}\,\lambda_{F,w,t}\,F_t \\ F_{t+1} = 0.5\,R_t\,A_{t+1} \end{cases}$$

The total number N_t of MU1 birds at 15 January in timestep *t* is given by

$$N_t = \lambda_{A,s,t}\,A_t + \lambda_{F,s,t}\,F_t$$

The total number N_t^C of geese (all three management units) observed in January in timestep *t* is derived using (deterministic) estimates of the summer populations of the Baltic and North Sea management units N_t^B and N_t^N. For these birds, a natural survival θ over period *s* is taken into account, as well as the regional derogation offtake rate from their populations, giving:

$$N_t^C = N_t + \left(1 - h_{s,t}^N\right)\theta N_t^N + \left(1 - \left(h_{s,t}^B + h_{s,t}^N\right)\right)\theta N_t^B$$

For natural survival rate θ a fixed, deterministic, value is used, obtained from preliminary capture-mark-resighting survival analysis for the Baltic and North Sea MUs.

The fraction π_t of juveniles at 15 January in timestep *t* is given by

$$\pi_t = \lambda_{F,s,t}\,F_t/\left(\lambda_{F,s,t}\,F_t + \lambda_{A,s,t}\,A_t\right) = \lambda_{F,s,t}\,F_t/N_t$$

The derogation offtake in period *s* in Baltic Sea region $H_{s,t}^B$ and in North Sea region $H_{s,t}^N$ are given by:

$$\begin{cases} H_{s,t}^B = h_{s,t}^B(\rho\theta_{F,s,t}F_t + \theta_{A,s,t}A_t + \theta N_t^B) \\ H_{s,t}^N = h_{s,t}^N(\rho\theta_{F,s,t}F_t + \theta_{A,s,t}A_t + \theta N_t^B + \theta N_t^N) \end{cases}$$

The derogation offtake in period *w* in Baltic Sea region $H_{w,t}^B$ and in North Sea region $H_{w,t}^N$ are given by:

$$\begin{cases} H_{w,t}^B = h_{w,t}^B \left[\begin{matrix} \rho\left(1 - \rho\left(h_{s,t}^B + h_{s,t}^N\right)\right)\theta_{F,s,t}F_t + \left(1 - \left(h_{s,t}^B + h_{s,t}^N\right)\right)\theta_{A,s,t}A_t + \\ \left(1 - \left(h_{s,t}^B + h_{s,t}^N\right)\right)\theta N_t^B \end{matrix} \right] \\ H_{w,t}^N = h_{w,t}^N \left[\begin{matrix} \rho\left(1 - \rho\left(h_{s,t}^B + h_{s,t}^N\right)\right)\theta_{F,s,t}F_t + \left(1 - \left(h_{s,t}^B + h_{s,t}^N\right)\right)\theta_{A,s,t}A_t + \\ \left(1 - \left(h_{s,t}^B + h_{s,t}^N\right)\right)\theta N_t^B + \left(1 - h_{s,t}^N\right)\theta N_t^N \end{matrix} \right] \end{cases}$$

This assumes that derogation offtake in period s is taking place after natural survival (including unknown Russian harvest) in period s, and that derogation offtake in period w occurs before natural survival (including unknown Russian harvest) in period w.

The model equations are presented in an alternative way, separately for the three MUs, in Table 4. The model also produces predictions of the derogation offtake for MU2 and MU3. However, these numbers and rates refer only to the derogation offtake that occurs while the birds of MU1 are present. MU2 and MU3 will be subject to additional derogation measures, e.g., in and around the breeding period.

Table 4. Overview of the population dynamic model for MU1 (column 2 and 3), with the equations used to calculate derogation offtake and the numbers at the end of the two periods making up annual timestep. The equations for MU2 and MU3 (column 4 and 5) are not part of the population dynamic model, but are used to account for the presence of MU2 and MU3 birds in the monitoring data (January counts and regional derogation offtake).

period	MU1 juveniles	MU1 adults	MU2	MU3
July	F	A	N^B	N^N
derogation s	$\rho\ (h_s^B + h_s^N)\theta_{F,s}F$	$(h_s^B + h_s^N)\theta_{A,s}A$	$(h_s^B + h_s^N)\theta N^B$	$h_s^N \theta N^N$
January	$\left(1 - \rho\ (h_s^B + h_s^N)\right)\theta_{F,s}F$	$\left(1 - (h_s^B + h_s^N)\right)\theta_{A,s}A$	$\left(1 - (h_s^B + h_s^N)\right)\theta N^B$	$(1 - h_s^N)\theta N^N$
January	F^1	A^1	N^{B1}	N^{N1}
derogation w	$\rho(h_w^B + h_w^N)F^1$	$(h_w^B + h_w^N)A^1$	$(h_w^B + h_w^N)N^{B1}$	$h_w^N N^{N1}$
July	$\theta_{F,w}\left(1 - \rho(h_w^B + h_w^N)\right)F^1$	$\theta_{A,w}\left(1 - (h_w^B + h_w^N)\right) A^1$	NA	NA

The main assumptions in the population dynamics model are:

- natural mortality (from natural causes and harvest in Russia) occurs before derogation in period s and after derogation in period w
- derogation mortality is additive to natural mortality
- derogation offtake occurs simultaneously in the Baltic and North Sea regions
- young birds are more vulnerable to derogation offtake than older birds, and the rate of differential vulnerability is constant

4. Integrated population model

The following yearly data were compiled in a single CSV file (Appendix E IPM data input file), with in parenthesis the name of the column in the CSV file and the corresponding model parameter in the IPM.

- January counts of the total flyway (Count, N_t^C);
- Number of observed juveniles in groups of known size (nFledgling, π_t)
- Group size for which the number of juveniles was observed (nGroup)
- Period s derogation offtake in the Baltic Sea region (hSummerBS, $H_{s,t}^B$)
- Period w derogation offtake in the Baltic Sea region (hWinterBS, $H_{w,t}^B$)
- Period s derogation offtake in the North Sea region (hSummerNS, $H_{s,t}^N$)
- Period w derogation offtake in the North Sea region (hWinterNS, $H_{w,t}^N$)
- Population counts in the North Sea region in the preceding summer in (NtNS1, N_t^N)
- Population counts in the Baltic Sea region in the preceding summer (NtBS1, N_t^B)

The IPM was implemented in JAGS 4.3.0 (Plummer 2003) which was run from within the R computing environment version 3.6.0 (Team 2019) employing the R package runjags (Denwood 2016). The full R code, including reading and processing of the data, is given in Appendix E R/JAGS code.

The JAGS code for survival was split into years without derogation offtake, for which total survival equals natural survival (including unknown Russian harvest), and years with derogation offtake for which total survival is the product of natural survival and the derogation offtake rate. The number of MCMC runs was imported from a separate file with the following settings:

adapt = 5000, burnin = 100000, sample = 100000, thin = 1, chains = 3.

With these settings a single run takes about 6 hours.

5. Data likelihoods and prior distributions

5.1 Prior for initial population size

The initial value for the "true" number of juveniles F_1 and adults A_1 in the first year are commonly chosen to be close to the population counts. However, only an initial total count of juveniles + adults is available and therefore this total count needs to be subdivided in some way. The percentage juveniles can be calculated from the data used in section 2.4, and this gives a long-term October mean of 15% for the years from 1974/75 to 2018/19. We used this percentage for subdivision of the initial population size. With an initial population count of around 40,000, this results in 6,000 juveniles and 34,000 adults. Using these values as means, employing a lognormal distribution and assuming a coefficient of variation of 50% for juveniles and 20% for adults, results in a 95% prediction interval for juveniles of (2,126, 13,545) and (22,614, 49,151) for adults. These intervals seem wide enough as initial population sizes. The resulting priors for the initial population size are then given by, in JAGS notation:

```
nF[1] ~  dlnorm(8.70, 4.48)
nA[1] ~  dlnorm(10.43, 25.50)
```

The mean and precision of these lognormal distribution are obtained by means of

```
mean       =  log(initialNumber) – 0.5*log(1 + CV*CV)
precision  =  1/log(1 + CV*CV)
```

5.2 Prior for survival

This section concerns the natural survival rates $\theta_{F,s}$, $\theta_{F,w}$, $\theta_{A,s}$ and $\theta_{A,w}$ for juveniles and adults in period s and w. These rates include unknown Russian harvest but exclude derogation in the Baltic and North Sea regions. It was envisaged that the survival rates (total survival, i.e. including derogation in the Baltic and North Sea regions) given in Table 1 could somehow be used as fixed priors for the survival rates in the IPM. However, there are three problems with such an approach. First, the confidence intervals in Table 1 are small, especially for adults, which would result in narrow prior distributions. This might disregard the possibly large year-to-year variation. Secondly, one of the purposes of the IPM is to use it for future years to see how the population will evolve under different scenarios. When highly informative priors for the survival rates would be employed, nothing will be learned about these rates from fitting the model. Thirdly, the rates in Table 1 include derogation while rates excluding derogation are required in the IPM. Therefore an alternative approach was used which employs a so-called random effects model for the natural survival θ. This assumes that the year-to-year rates are drawn from some distribution with hyper parameters. It is common to define a model for a probability, like the survival rate, on the logit scale. In JAGS code such a model reads, for instance for Fledglings summer survival:

```
meanLogit.F.s    ~    dnorm(μFs, τFs)
sigmaLogit.F.s   ~    dunif(0, σFs)
tauLogit.F.s   =   1/(sigmaLogit.F.s * sigmaLogit.F.s)
for (t in 1:nyears) {
  logit.theta.F.s[t]     ~   dnorm(meanLogit.F.s,  tauLogit.F.s)
  logit(theta.F.s[t])   =   logit.theta.F.s[t]
}
```

In this case no distinction is made between survival before and after 2007. Instead the year-to-year survival parameters are drawn from a normal distribution with parameters *meanLogit* and *tauLogit* which themselves follow hyper prior distributions with fixed parameters μ, τ and σ. The idea is that the yearly probabilities do differ, but they also have something in common namely a shared underlying distribution. The Bayesian analysis hopefully learns something from the data about this shared distribution, and the posterior distributions of *meanLogit* and *tauLogit* can then be used for future simulations of the population. This approach assumes that the mean and variance are constant over time. Alternatively, a trend in time could be modelled by e.g. $\mu = \alpha_\mu + \beta_\mu \times Time$ in which case priors for α_μ and β_μ would be required.

The question then is what to choose for the fixed meta parameters μ, τ and σ. Note that the median of the distribution of the survival rate θ equals ilogit(μ) where ilogit() is the inverse of the logit() function. Examples of the resulting distribution of the survival rate for various values of the meta parameters μ, τ and σ are given in Figure 8. Here, the parameter μ was chosen such that the median of the distribution of the survival rate θ equals 0.6 (left panels), 0.75, 0.90 and 0.95 (right panels). The top bar in every plot is obtained by a fixed value "*sigmaLogit* = σ/2", while the bottom bar is obtained by also simulating "*sigmaLogit* ~ dunif(0, σ)". The bottom distribution is, by definition, somewhat wider than the top distribution. Despite the rather small confidence intervals in Table 1, the following wide priors were chosen depicted with a grey background in Figure 8: σ=4, τ=4 and μ=0.41 for Fledglings (with median survival 0.6) and σ=4, τ=4 and μ=2.20 for adults (with median survival 0.9). The same priors were chosen for summer and winter survival. For the chosen values, there is little difference between the top and bottom bars in Figure 8. Therefore the more simple case with a fixed value "*sigmaLogit* = σ/2" was used.

5.3 Prior for reproduction

For the reproduction rate R_t a similar approach as for the natural survival rate θ_t was chosen, i.e. a random effects model with a hyper prior. The only difference is that the reproduction rate can be larger than 1. It was assumed that the reproduction rate cannot be larger than 2, and a random effects model is then given by, in JAGS notation:

```
meanLogit.R      ~  dnorm(μR, τR)
sigmaLogit.R     ~  dunif(0, σR)
tauLogit.R       =  1/(sigmaLogit.R * sigmaLogit.R)
for (t in 1:nyears) {
      logit.repro[t]    ~     dnorm(meanLogit.R, tauLogit.R)
      repro[t]          =     2/(1+exp(-logit.repro[t]))
}
```

The only difference with the random effects model for survival is that the reproduction repro[t] is multiplied by 2 giving values in the interval (0,2) rather than (0,1). Again, the question is what to choose for the fixed hyper parameters μ, τ and σ. The estimated survival rates in Table 1 were used to get some idea of the population development for various fixed reproduction rates R. This employs the deterministic model given in Figure 7, starting with 700,000 individuals in Mid-June 2007, of which 15% are Juveniles. This exercise suggests that a reproduction rate of around one is required to obtain a growing population for the last 10 years. The parameter μ_R was therefore set to zero implying a median reproduction rate of one. Prior distributions with $\mu_R = 0$ and various values of τ_R and σ_R are given in Figure 9. The distribution with $\mu_R = 0$, $\tau_R = 2$ and $\sigma_R = 2$, depicted with a grey background in Figure 9, seems reasonably uninformative and was therefore chosen. Again, for these chosen values there is not much difference between the top and bottom bars, and therefore the more simple case with a fixed value “*sigmaLogit* = *σ*/2” was employed.

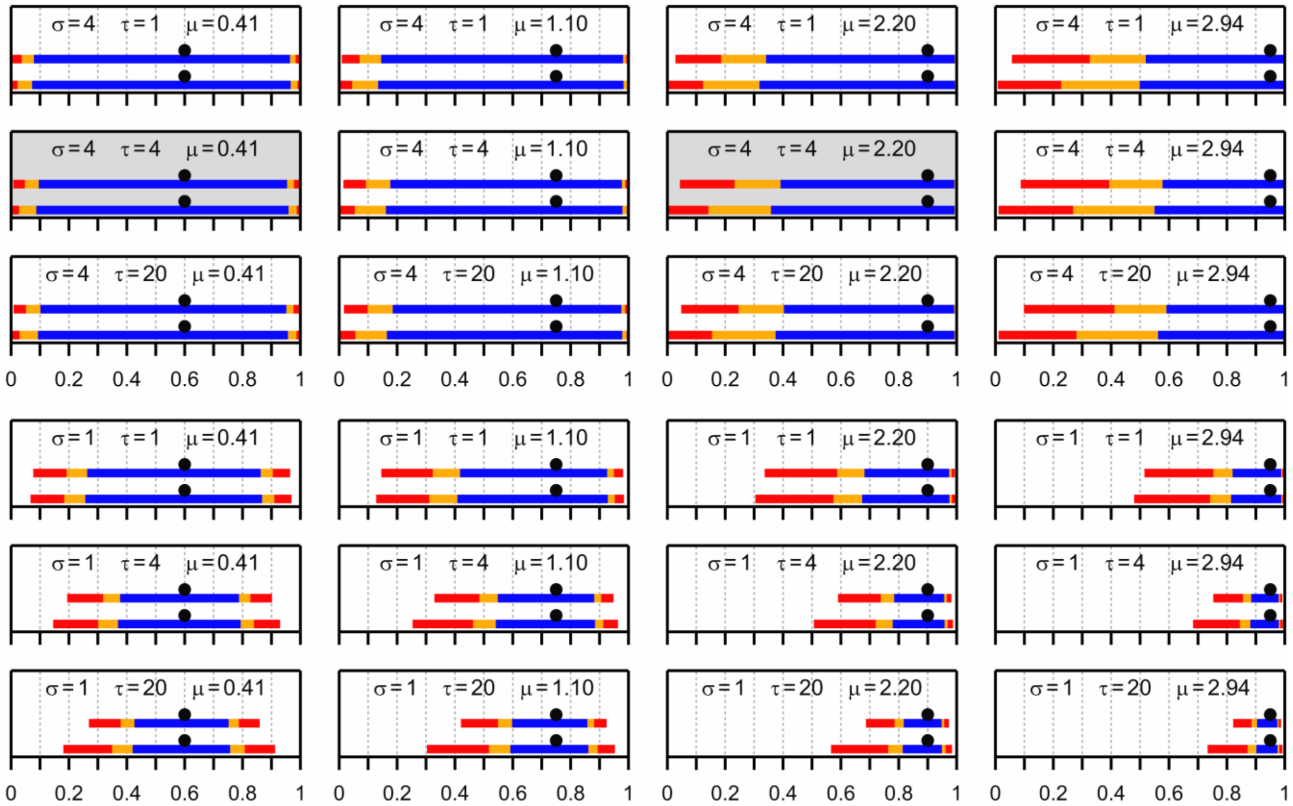

Figure 8: Prior distributions for the natural survival rate θ for various values of the fixed hyper parameters μ, τ and σ. The blue bar represents 80% of the distribution, and the orange/red bars extend to 90/99% of the distribution. The black dot depicts the median. The different values of μ are such that the median probability equals 0.6, 0.75, 0.9 and 0.95 (left to right panels). The top bar in every panel is obtained by employing a fixed value "*sigmaLogit* = σ/2", while the bottom bar is obtained by simulating "*sigmaLogit* ~ dunif(0, σ)". The panels with a grey background depict the chosen priors for Juveniles (μ=0.41) and Adults (μ=2,20) respectively.

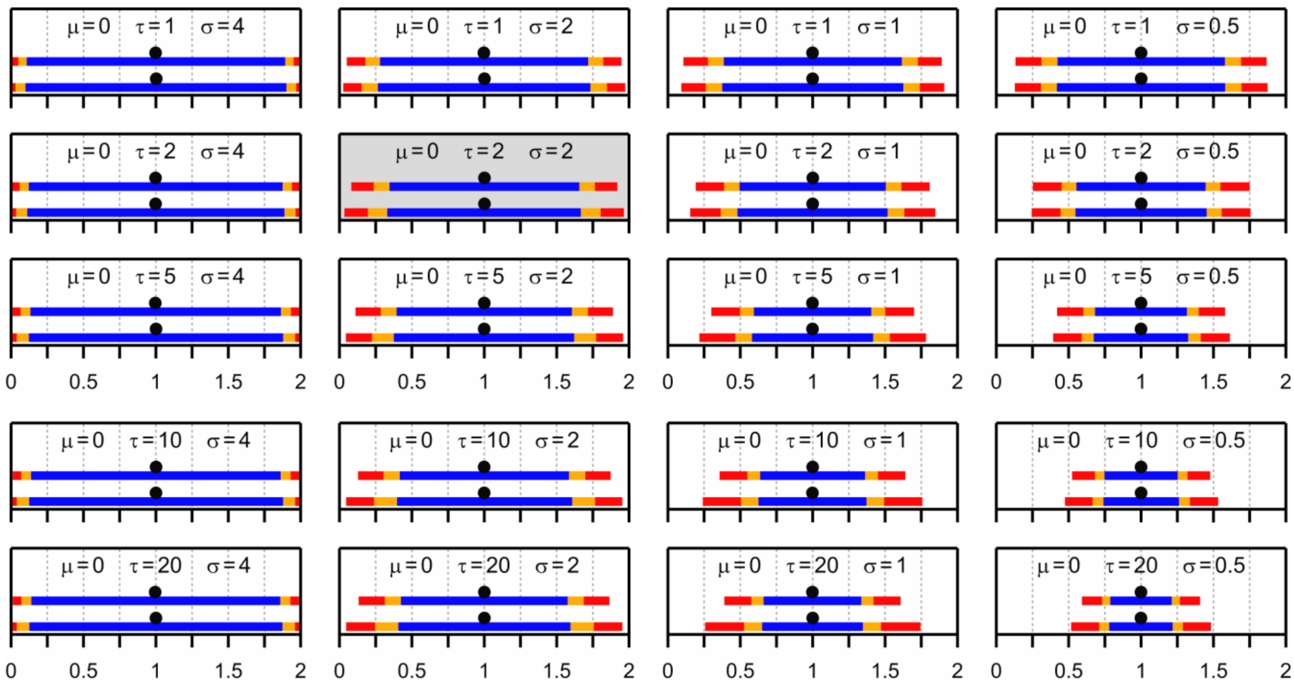

Figure 9: Prior distributions for the reproduction parameter R for various values of the fixed meta parameters μ, τ and σ. The parameter μ was set to zero such that the median reproduction rate equals one in all panels. See Figure 8 for a further description. The panel with a grey background depicts the chosen prior.

5.4 Prior for derogation offtake rates

Before 2007 there was no derogation offtake. After 2007 total observed derogation offtake relative to counts of the total flyway population was always smaller than 3%. Uninformative uniform priors between 0 and 10% were employed for the yearly derogation offtake rates in the Baltic and North Sea regions both in period s and w, i.e. for the parameters $h^B_{s,t}$, $h^N_{s,t}$, $h^B_{w,t}$, $h^N_{w,t}$. These uninformative priors allow the model to deviate from the observed derogation offtake rates.

5.5 Observation error January counts

The total number of geese N^C_t of all three MUs in January, defined by the population model, has to be linked to the observed January counts Y_t. Since Y_t is measured with error the link employs a statistical distribution. This is called the *observation error* in the IPM terminology and reflects both error in the counts and lack of fit of the model. For large counts, such as for the Barnacle Goose, it is common to specify a logNormal distribution for the error. A logNormal(μ, σ^2) distribution has median $\exp(\mu)$, mean $\mathbb{E} = \exp(\mu + \sigma^2/2)$ and variance $\mathbb{V} = \mathbb{E}^2\,(\exp(\sigma^2) - 1)$. It follows that the coefficient of variation equals $CV = \sqrt{\mathbb{V}}/\mathbb{E} = \sqrt{\exp(\sigma^2) - 1}$. The inverse of the latter equation gives $\sigma^2 = \log(CV^2 + 1)$. In the JAGS model the parameter μ of the lognormal distribution is set to the logarithm of N^C_t and we need a prior for the variance σ^2. We choose to specify a prior for CV instead because this is a more natural parameter.

Assuming that the observed January counts follow a more or less smooth function in time, the residuals from a fitted function then provide information about the error distribution. Fitting a smoothing spline in time with 2 degrees of freedom to the observed counts, employing a generalized linear model with the gamma distribution and a log-link, gives an estimate of 15% for the coefficient of variation, with very similar CV values for smoothing splines with 3 and 4 degrees of freedom. The fitted smoothing spline is depicted in Figure 10. Fitting the smoothing spline to the data before 2000 resulted in an estimate of the CV value of 17%, while the data after 2000 gives an estimate of 11%.

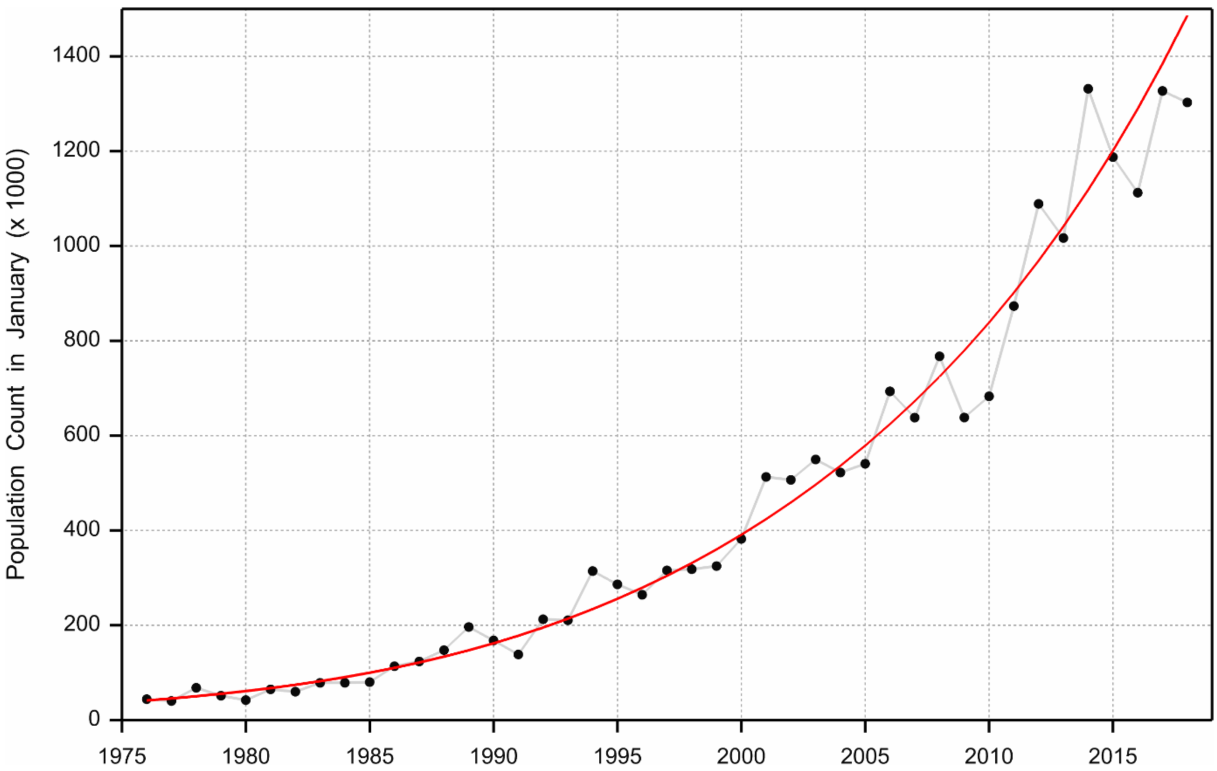

Figure 10: Observed January counts and fitted smoothing spline with 2 degrees of freedom employing a generalized linear model with the gamma distribution and a log-link.

These estimates of the CV value of the error of the January counts might be too large because the population model has ample room to follow the observed counts more closely. Therefore a gamma hyper prior for the CV value was employed such that a 98% prediction interval for the CV equals (5%, 20%). The R function gamma.parms.from.quantiles() (Belisle 2012) was employed to calculate the associated gamma parameters. In JAGS the inverse of the scale parameter, i.e. the rate parameter, is required. The R code to obtain the JAGS parameters is given by the following code which includes a check in the last two lines.

```
intervalCV    =  c(5, 20)
coverageProb  =  0.98
quantiles     =  c((1-coverageProb)/2, (1+coverageProb)/2)
parms         =  gamma.parms.from.quantiles(intervalCV/100, quantiles)
shapeCount    =  parms$shape
scaleCount    =  parms$scale
rateCount     =  1/scaleCount
print(cbind(shapeCount, scaleCount, rateCount))
cvCount       =  rgamma(100000, shape=shapeCount, scale=scaleCount)
quantile(100*cvCount, quantiles)
```

The resulting shape and rate parameters are 11.83 and 106.3 respectively. The JAGS code for the observation error of the January counts is then given by, with januaryCount[t] representing N_t^C and Count[t] the observed January count:

```
cvCount  ~  dgamma(11.83, 106.3)
log.tauCount  =  1/log(cvCount*cvCount + 1)
for (t in 1:nyears) {
    log.januaryCount[t] = log(januaryCount[t])
    Count[t] ~ dlnorm(log.januaryCount[t], log.tauCount)
}
```

5.6 Observation error derogation offtake

Johnson et al. (2020) employed a Poisson distribution for the offtake divided by 100. The derogation offtake data analysed here ranged from 1000 to 13000, giving "Poisson" numbers between 10 and 130. The coefficient of variation CV for Poisson distributions with means λ = 10, 20 … 130 are given in Table 5. Such CV values seem rather small, especially because observed derogation numbers are possibly prone to bias due to underreporting or overreporting. Therefore, employing the same approach as for the error for the January counts, a gamma prior was used with a 98% prediction interval for the CV equalling (5%, 40%). The resulting shape and rate parameters are 5.558 and 31.12 respectively. The same hyper prior was employed for the four derogation counts in the Baltic and North Sea regions as well as in period s and w, i.e. for the parameters $H_{s,t}^B$, $H_{s,t}^N$, $H_{w,t}^B$, $H_{w,t}^N$.

Table 5: *Coefficient of variation CV for a Poisson distribution with mean λ.*

λ	10	20	30	40	50	60	70	80	90	100	110	120	130
CV	32	22	18	16	14	13	12	11	11	10	10	9	9

5.7 Observation error number of juveniles in groups of known size

A beta-binomial distribution was employed for the observed number of juveniles with binomial totals the corresponding group size and probability of success π_t which is given in the IPM model. Following Johnson et al. (2020), the parametrization used for the Beta distribution is: $\alpha_t = \omega\, \pi_t$ and $\beta_t = \omega\,(1 - \pi_t)$ where ω is the temporally constant over-dispersion parameter, see section 2.4. An informative prior for ω was derived from the ω data in Table 2. A gamma distribution was fitted to these data giving estimates shape=2.6635 and rate=0.059374, and these values were used as prior for ω. Figure 11 displays the values of the yearly over-dispersion parameter ω given in Table 2 (vertical bars) along with a graphical depiction of the fitted gamma distribution. Note that there are only 22 observed ω values and therefore the fitted distribution extends above the minimum and maximum of the observed values.

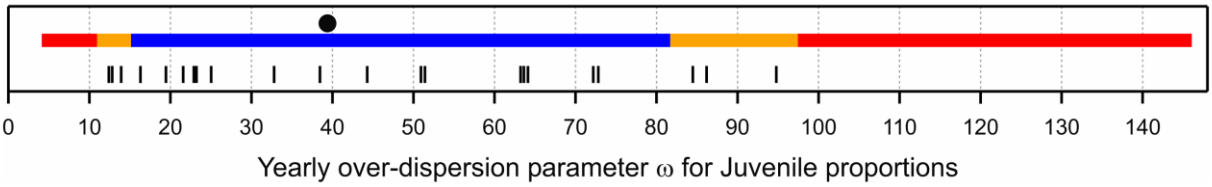

Figure 11: Observed yearly over-dispersion parameter ω (vertical bars) of the Beta distribution for juvenile proportions excluding the season 2000/01. Fitted gamma distribution (horizontal line) where the dot denotes the median of the distribution, the blue bar represents 80% of the fitted distribution, and the orange/red bars extend to 90/99% of the distribution.

The JAGS code for the observed number of juveniles in a group is then as follows, in which pFledgling[t] is the proportion according to the model, and nFledgling[t] is the number of observed juveniles in a group of nGroup[t] individuals:

```
shapeFledgling   = 2.6635
rateFledgling    = 0.059374
dispFledgling    ~ dgamma(shapeFledgling, rateFledgling)
for (t in 1:nyears) {
   propFledgling[t] ~ dbeta(dispFledgling * pFledgling[t], dispFledgling * (1-pFledgling[t]))
   nFledgling[t]    ~ dbin(propFledgling[t], nGroup[t])
}
```

6. Results

6.1 Results of the Integrated Population Model

For all the monitored parameters the potential scale reduction factor (psrf) was in the interval (1.000, 1.003) indicating convergence of all parameters. Posterior means and 95% credible intervals for the demographic rates of the Russian population are depicted in Figure 12 to Figure 18.

Figure 12 reveals that the January counts of the total flyway population are well represented by the model although there are some counts, 2011/12 and 2013/14, which are outside the posterior 95% interval. However, these counts are possibly “too large” when compared to counts in surrounding years. Before 2000, the January posterior means of the arctic population are almost identical to the posterior means of total flyway population which is in accordance with the small size of the North Sea and Baltic populations in that period. In the last four years, the total flyway population and the Russian population both seem to level off, the latter at a level of around 1 million birds.

Figure 13 shows that, due to the assumed overdispersion of the beta-binomial distribution, the yearly posterior 95% intervals of the proportion juveniles in October to January are quite wide and that all observed proportions are within the intervals. After considerable variation until the year 2000, the proportion juveniles seems to stabilize from 2000 onwards. The mean proportion for the season 2006/07 and onwards equals 0.12.

Figure 14 reveals that the yearly posterior intervals for the reproduction rate R_t roughly varies between 0.2 and 1.2 fledglings/adult pair. The reproduction rate is mostly below 1, the median of the assumed prior. Again, from 2000 onwards, the reproduction is more or less stable; this goes hand in hand with the stable proportion of juveniles in later years in Figure 13. The mean reproduction for the season 2006/07 and onwards equals 0.54.

Figure 15 shows the mean posterior survival rates θ for juveniles and adults. Adult survival is more or less constant across the years and there is not much difference between survival in period *s* and *w*. Juvenile survival in period *w* is generally smaller than in period *s* and is also more variable across years. Table 6 lists the estimates of NIOO (Table 1) for the total survival (including harvest in EU) and the mean of the yearly posterior means for the period before and after 2007 of the natural survival (excluding harvest in EU but including the unknown Russian offtake). The difference should be in the harvest rate in EU (Baltic and North Sea region), see below.

Figure 16 depicts mean posterior survival rates along with the accompanying 95% credible intervals. The intervals for juveniles are quite wide, generally between 0.3 and 1.0. The intervals for adults are roughly given by (0.9, 1.0). Note that the length of the intervals more or less depends on the posterior mean, with smaller intervals for posterior means close to 1 and wider intervals for posterior means in the vicinity of 0.5. This is a direct consequence of the formulation of survival rates in the IPM as logit-transformed normal variables.

Figure 17 shows posterior means and accompanying intervals for derogation offtake (top panels) and derogation offtake rates (bottom panels) both in the North Sea and the Baltic Sea region. All reported offtake is within the 95% intervals. The intervals in period *w* are quite wide at the end of the observation period. Mean posterior derogation offtake rates for the more recent years are around 0.5% in period *s* and around 1.5% in period *w* with some differences between the two regions.

Figure 18 compares the priors and posteriors for the hyper parameters for the survival (natural survival including unknown Russian harvest) and reproduction rates, the coefficient of variation of the error distribution for January population counts and harvest numbers, and the dispersion parameter of the beta-binomial distribution of the observed number of juveniles in groups of known size. The posteriors for juvenile survival in period *s* and period *w* are shifted to the right implying that survival rates are larger than envisaged by the prior. Survival of juveniles is somewhat larger in period *w* than in period *s*. The posteriors of adult survival in periods *s* and *w* are very similar; they are also shifted to the right as compared to the priors. The posterior for the reproduction rate is shifted to the left and is much narrower than the prior, so the IPM model learned something along the way. The posterior of the CV value for the January counts is shifted to the right, but still in the range of the prior. This indicates that a wider prior for this parameter will probably not make a big difference. The posterior of the CV value for the derogation offtake is shifted to the right and much wider than the prior.

Finally, Figure 18 reveals that the posterior for the overdispersion parameter of the beta-binomial distribution is more or less equal to the prior. This is not surprising because a good fitting model to detailed data was used to obtain this prior.

From the results obtained for the last decade, the MU1 population appears to combine a relatively low mean productivity (0.54 fledglings / adult pair), a high mean natural survival rate (including offtake in Russia) for adults (*s*: 0.9771; *w*: 0.9690) and a low mean natural survival rate (including offtake in Russia) for juveniles (*s*: 0.6215; *w*: 0.7727). Derogation offtake rates may have increased to around 1% (period *s*) and around 3% (period *w*), summed over Baltic and North Sea regions. Overall, the combination of reproduction, survival and derogation offtake rates appears to result in a levelling off of population growth (Figure 12).

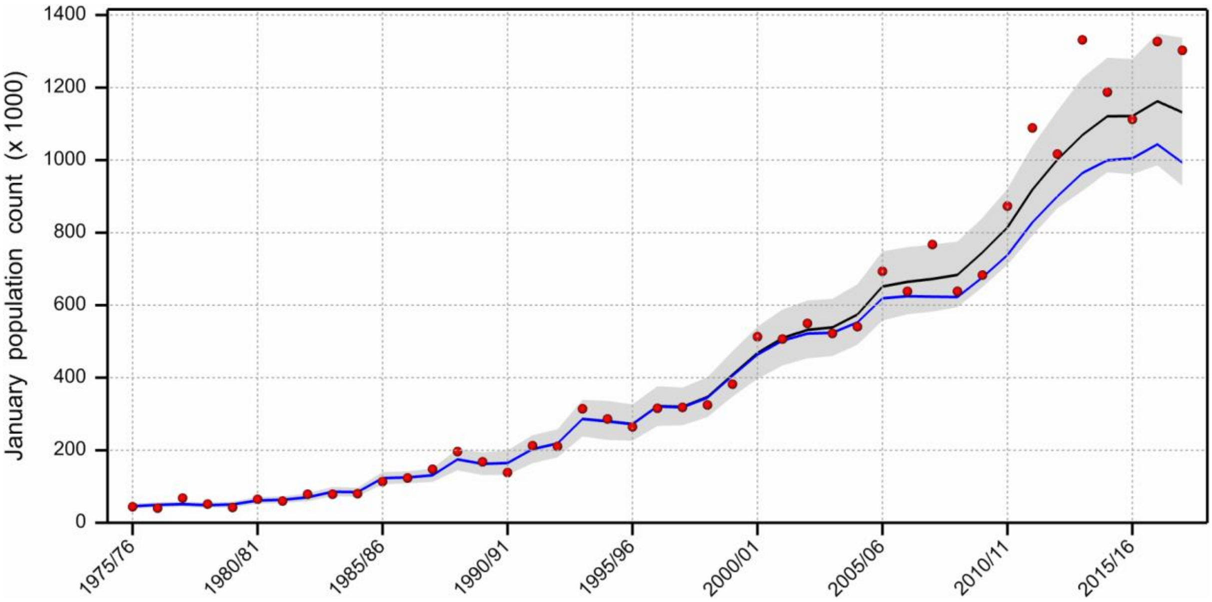

Figure 12: January total flyway population counts (red dots), posterior means (black line) and posterior 95% intervals (grey area) along with the January posterior means of the arctic population (blue line).

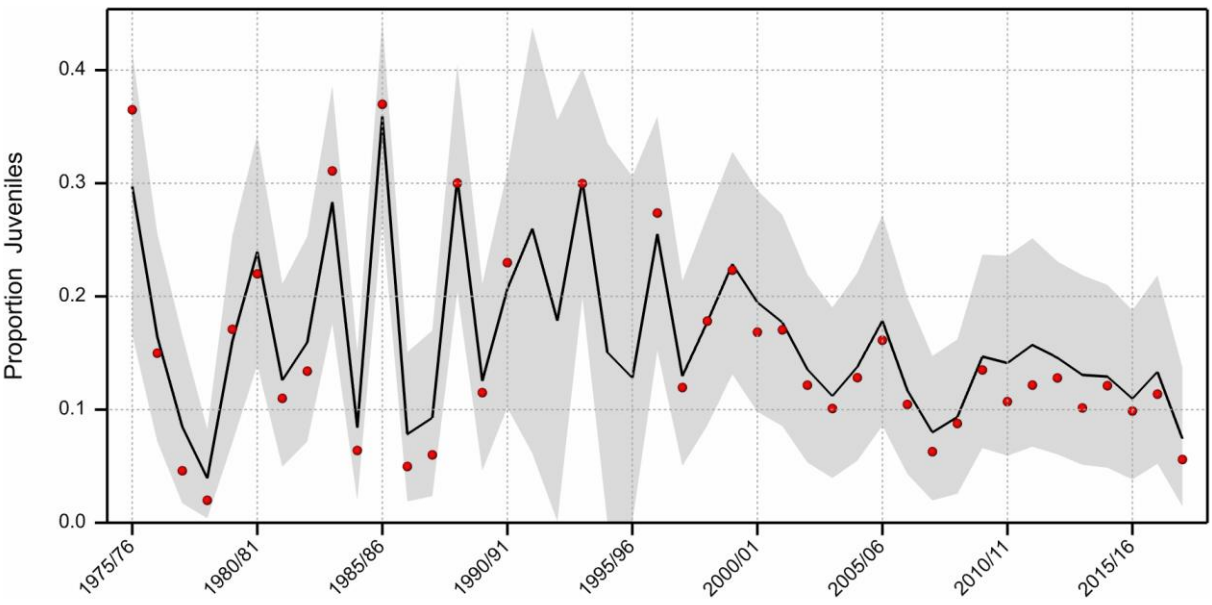

Figure 13: Observed proportion Juveniles (red dots) in the Netherlands and the German Dollard region in October to January, posterior means (black line) and posterior 95% intervals (grey area).

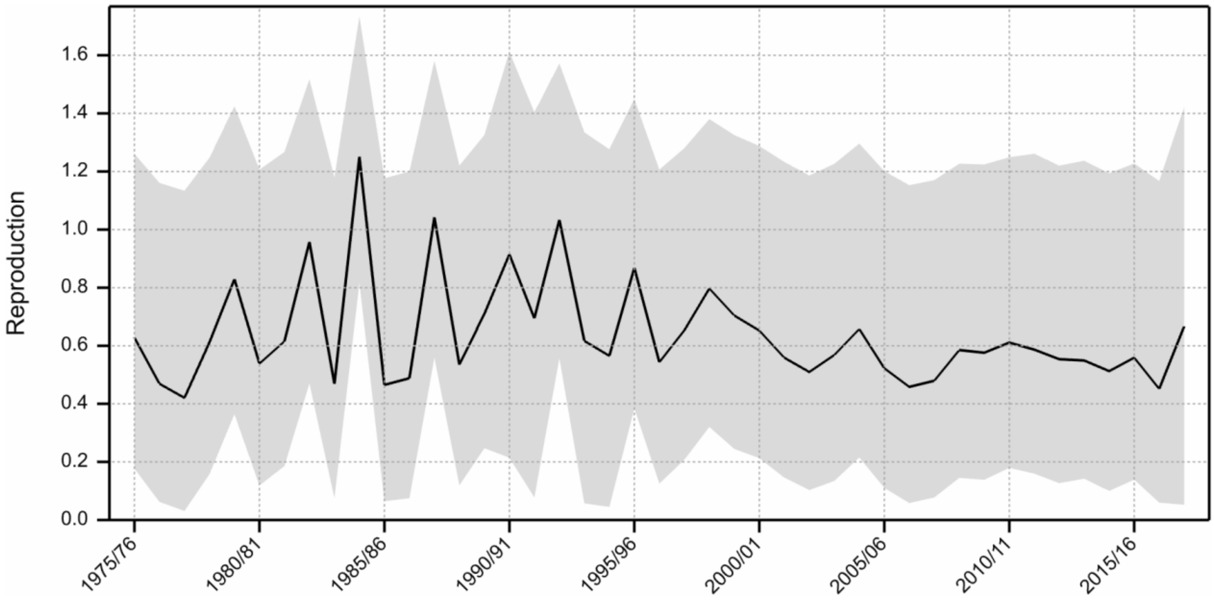

Figure 14: Posterior means and posterior 95% intervals for the reproduction rate of the MU1 population.

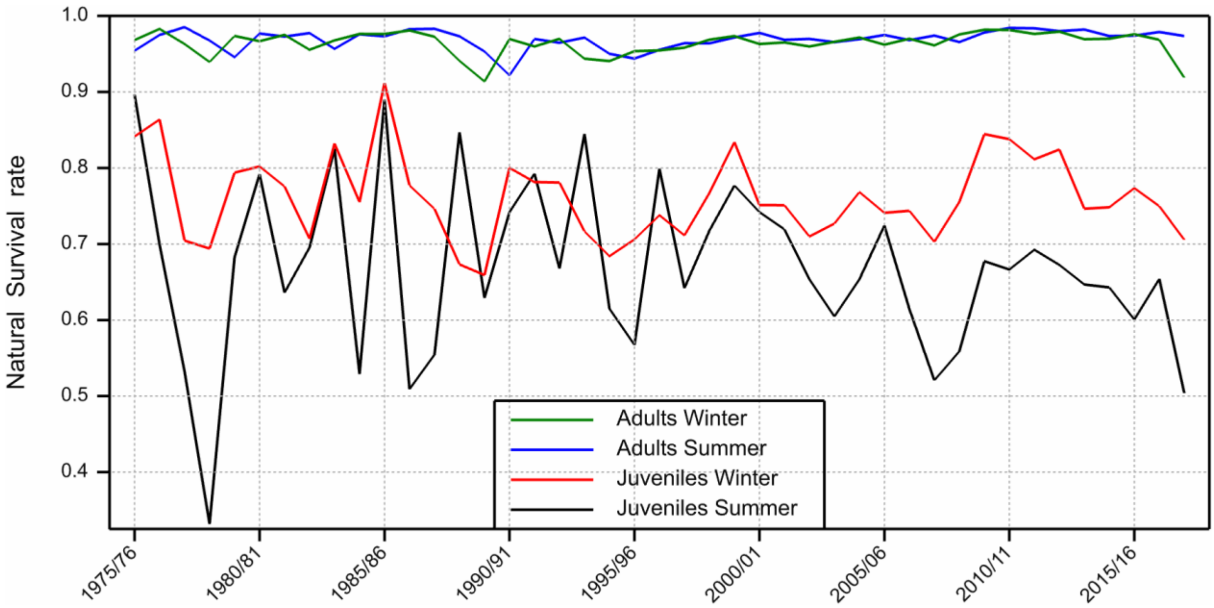

Figure 15: Posterior means for the natural survival (including unknown offtake in Russia) for juveniles and adults in period *w* ("winter") and period *s* ("summer").

Table 6: Estimated *total* survival rates by NIOO (NIOO Esti), *natural* survival rates (including unknown Russian harvest) from the IPM (IPM Esti), and *total* survival rates estimated from the IPM (IPM Esti_total). Only the total survival estimates include the derogation offtake rates. Values are categorized by stage, summer/winter and observation period (before or after 2007).

Stage	Summer/Winter	Period	NIOO Esti	IPM Esti	IPM Esti_total
Juvenile	Summer	Before 2007	0.7438	0.6852	
Juvenile	Winter	Before 2007	0.9662	0.7578	
Adult	Summer	Before 2007	0.9687	0.9664	
Adult	Winter	Before 2007	0.9751	0.9626	
Juvenile	Summer	After 2007	0.4871	0.6215	0.6169
Juvenile	Winter	After 2007	0.8785	0.7727	0.7553
Adult	Summer	After 2007	0.8906	0.9771	0.9734
Adult	Winter	After 2007	0.9244	0.9690	0.9579

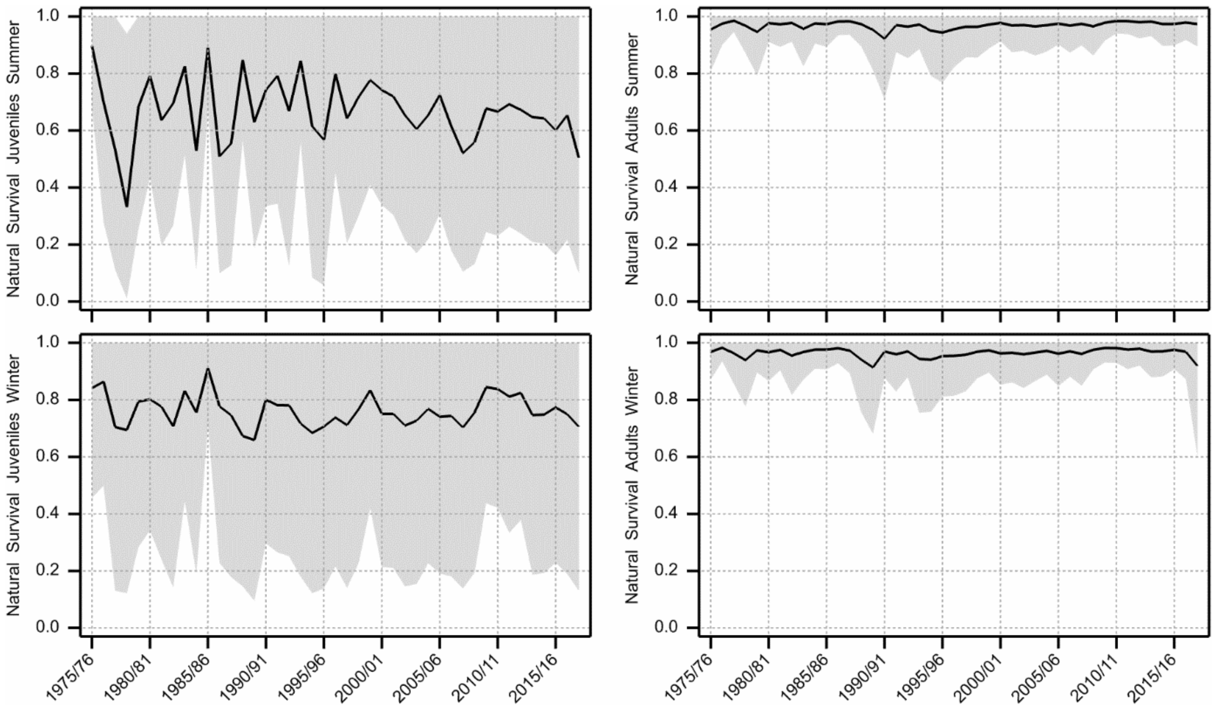

Figure 16: Posterior means and posterior 95% interval for natural survival (including unknown offtake in Russia) for juveniles and adults in period *w* ("winter") and period *s* ("summer") in the arctic population.

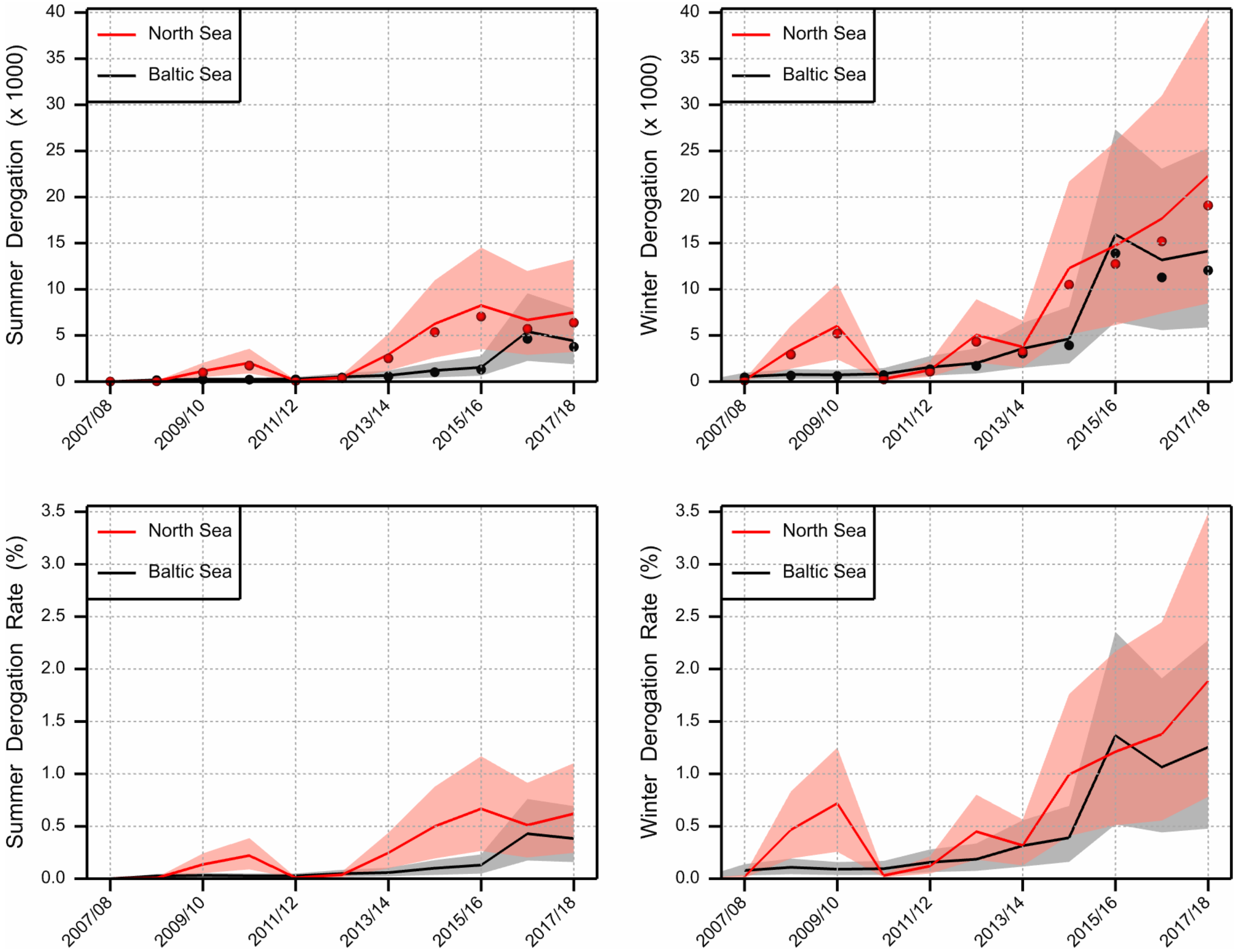

Figure 17: Top panels: observed derogation offtake numbers in the North Sea (red dots) and the Baltic Sea (black dots) regions along with posterior means (lines) and posterior 95% intervals (areas). Bottom panels: derogation offtake rates with posterior means and posterior 95% intervals.

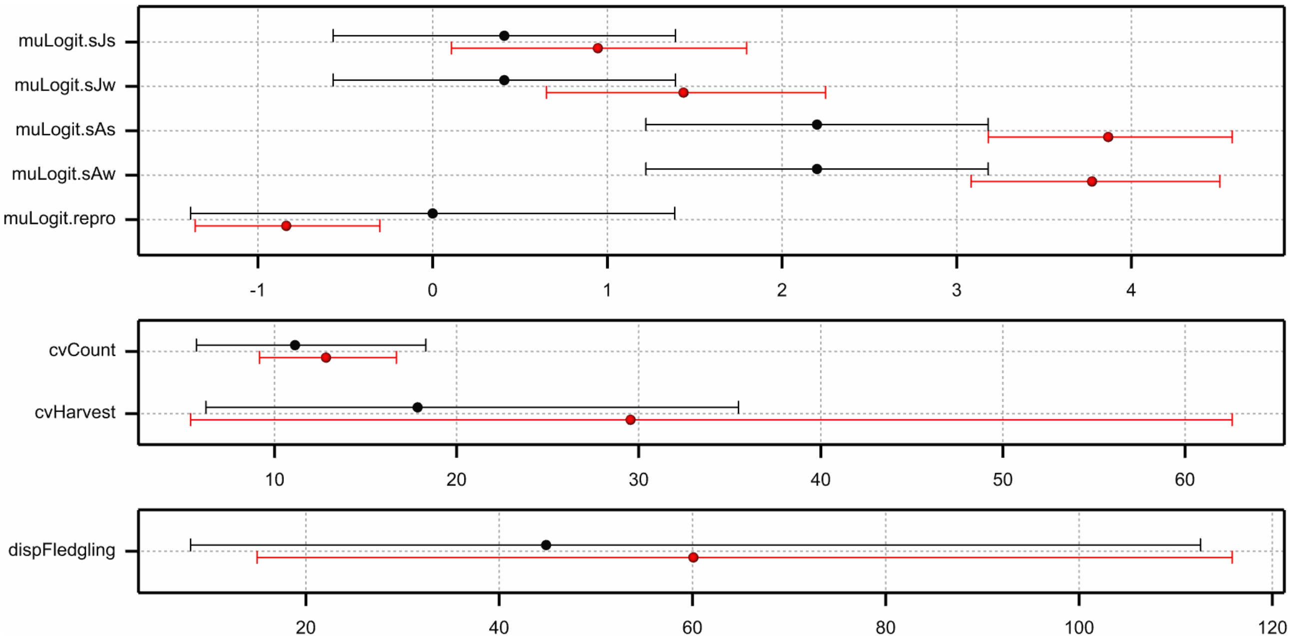

Figure 18: 95% intervals and means for the prior (black) of the hyper parameters along with the 95% interval and means of the posterior (red).

6.2 Scenario analysis

The results of the IPM can be employed to simulate how the population will evolve in future years under different derogation scenarios. There are two ways to go about this: (1) simulating future years internally in the IPM, or (2) employing the posterior distributions of survival, reproduction and population numbers in the final year to simulate future years external to the IPM. (Kéry and Schaub 2012)) advocate the first approach such that all uncertainties are properly propagated. However, it was found that, for the IPM at hand, the two approaches are indistinguishable for simulating future years without derogation. Therefore the second approach was followed because this only requires a single run of the JAGS model and is thus much more flexible in examining different scenarios. The second approach requires:

- The number of juveniles and adults with which to start the simulation. For this the IPM posteriors of these numbers in the final year, i.e. July 2017, were taken.
- The posteriors for the survival and reproduction hyperparameters (meanLogit.F.s, meanLogit.F.w, meanLogit.A.s, meanLogit.A.w and meanLogit.R) since these define the information we have obtained about the year-to-year variation in these rates.
- The derogation offtake rates, which will be imposed. The following derogation offtake scenarios were simulated: (1) no derogation offtake, (2) derogation offtake rate in period *s* of 0.5% and in period *w* of 1%, (3) rates 1% and 2% in period *s* and *w* respectively, and (4) rates 1% and 3% in period *s* and *w*. The latter scenario is more or less according to the mean posterior derogation offtake rates in the final season, see Figure 17.

The posteriors, obtained by running the IPM, for the final numbers of juveniles and adults, the survival rates and the reproduction rate were thinned by a factor 3 leaving 100,000 draws from each posterior. For each draw a trajectory of the total number in January, i.e. halfway a season, was simulated for 10 future years according to the stage-structured life cycle of Figure 7. This involves simulation of survival rates and a reproduction rate separately for each year. For example with sFs[1] the first sample of the posterior of the hyper parameter meanLogit.F.s for juveniles in summer, a separate survival rate $\theta_{F,s,t}$ is simulated for each year t=1…10. This employs the pseudo code $\theta_{F,s,t}$ ~ ilogit(dnorm(sFs[1], sigma=4)). The 100,000 trajectories were then summarized by their mean, median, 50% and 90% central interval, giving Figure 19 for the four harvest scenarios. This reveals that the uncertainty in the initial population size, as represented by the posterior, is becoming larger and larger when time progresses such that it seems hazardous to draw firm conclusions. However, for the largest derogation offtake rates there is a risk that the population will decline.

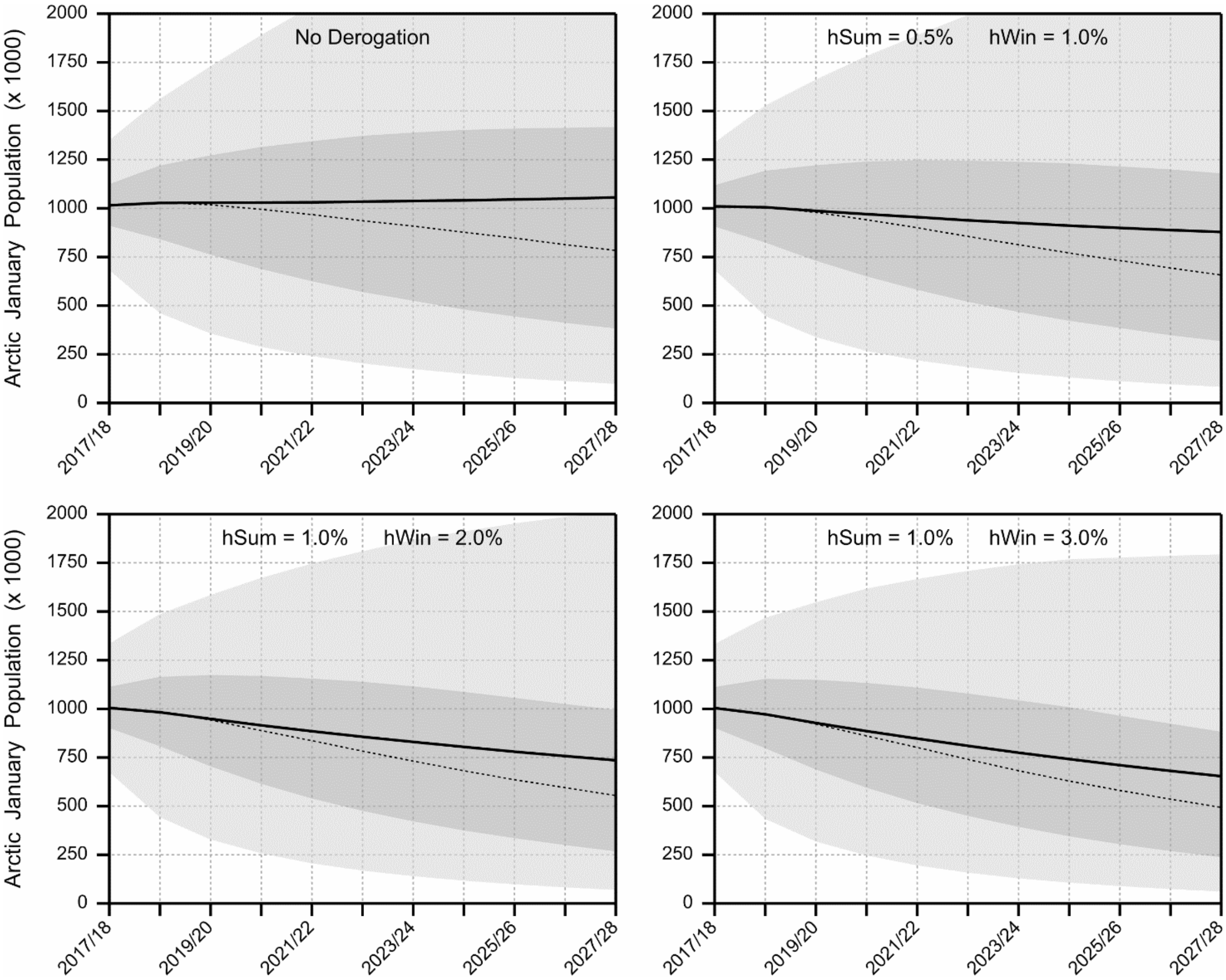

Figure 19: Mean (solid line), Median (dotted line), 50% central interval (grey) and 90% central interval (light grey) of 100,000 simulated future trajectories of MU1 population for four derogation offtake scenarios, with different offtake percentages in period *s* ("Sum") and *w* ("Win"), employing the original posteriors for the hyper parameters.

The posteriors for the hyper parameters are derived from the data for the full 43 year period. However, Figure 14 (reproduction) and Figure 15 (survival) indicate that at the end of the observation period the survival of adults might be somewhat larger, the survival of juveniles somewhat smaller and the reproduction rate also seems somewhat smaller. Therefore, in a second simulation, the posteriors of the hyper parameters were shifted such that the median of each posterior equals the median of the logit transformed samples (see e.g. Figure 16) for the last ten years. Figure 20 compares simulated survival and reproduction rates according to the original and according to the shifted posterior. This shows that the shift mainly increases survival of adults. The scenario analysis employing the shifted posteriors is summarized in Figure 21. For the largest derogation offtake percentages the population declines somewhat, but again there is considerable variation.

For both tested situations, there is a large difference after 10 years between the "No derogation" scenario and the derogation offtake scenario with 1% in summer and 3% in winter.

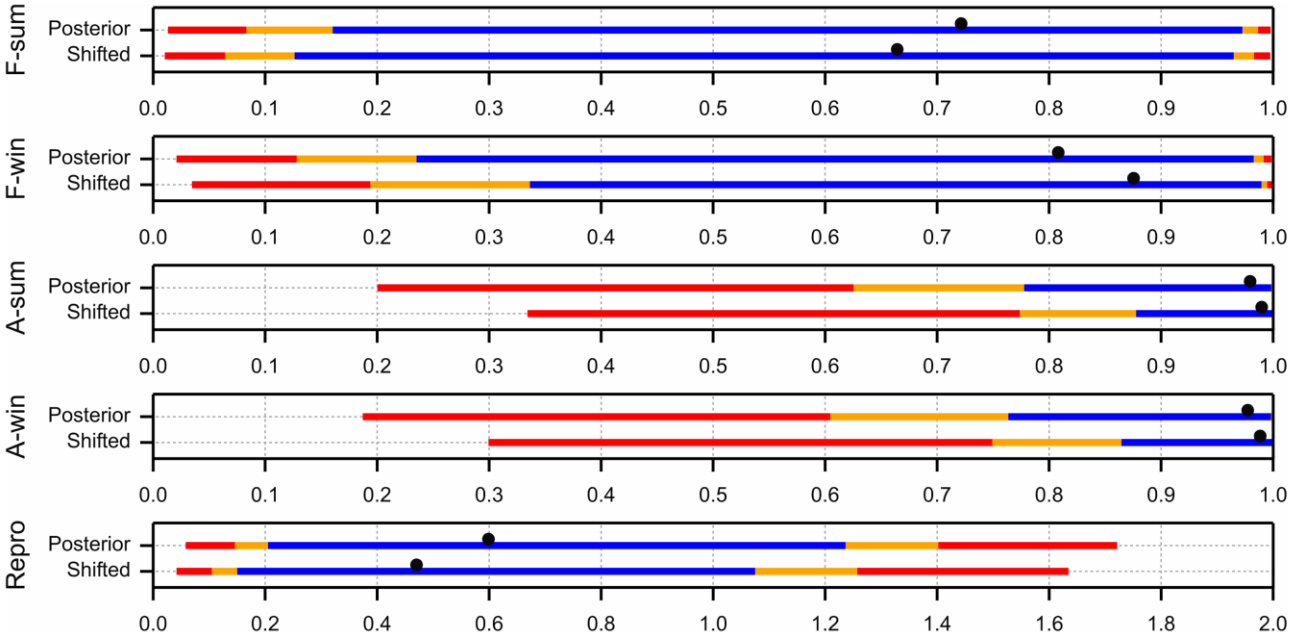

Figure 20: Distributions of survival (natural survival including unknown Russian harvest) in period *s* ("-sum") and *w* ("-win"), of juveniles (F) and adults (A), and of the reproduction rate according the original posterior distribution and according to the shifted posterior distribution. The black dot denotes the median, the blue line the 80% central interval, which is extended towards the 90/95% interval by the orange/red lines.

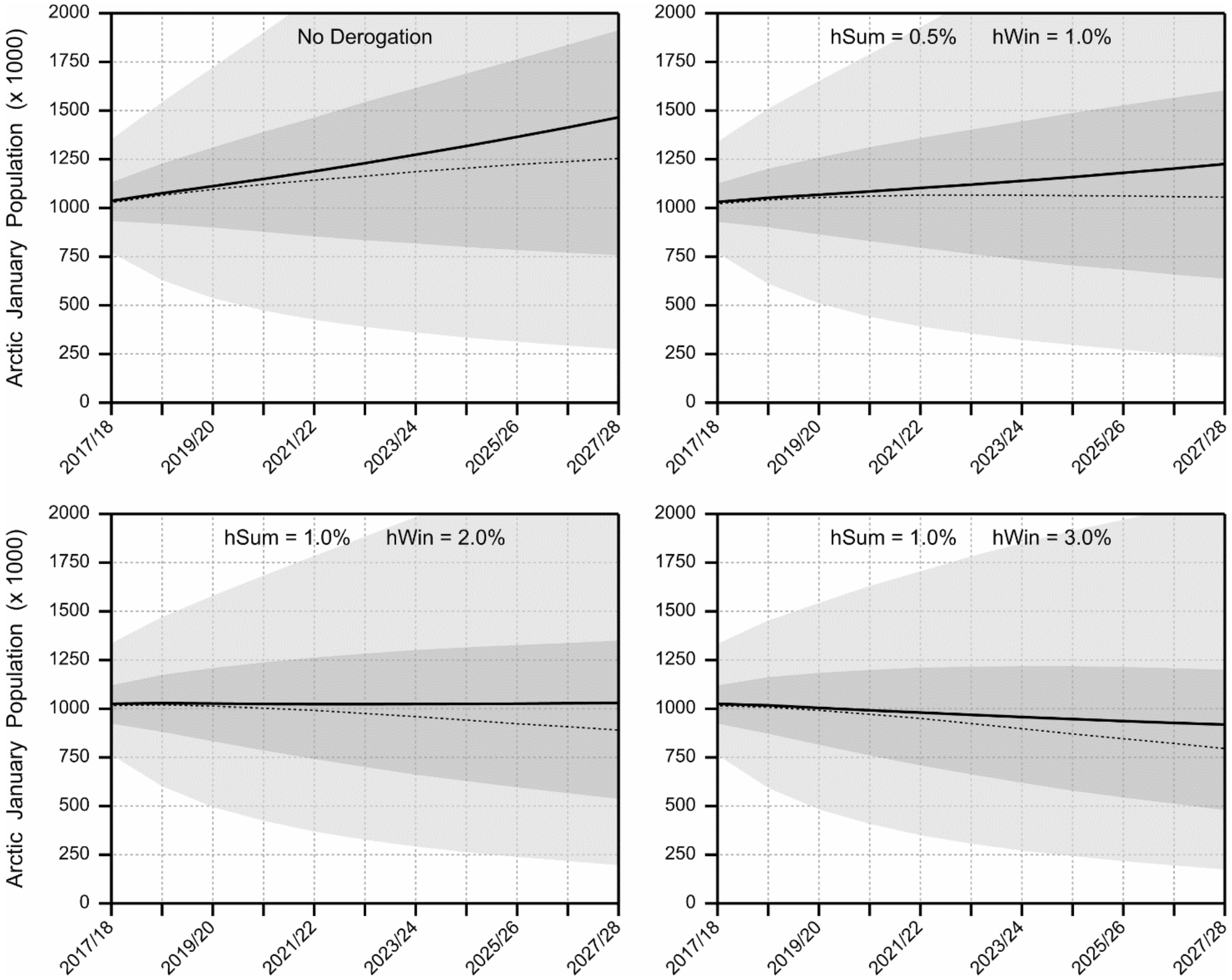

Figure 21: Mean (solid line), Median (dotted line), 50% central interval (grey) and 90% central interval (light grey) of 100,000 simulated future trajectories of the MU1 population for four harvest scenarios, with different derogation offtake percentages in period *s* ("Sum") and *w* ("Win"), employing the shifted posteriors for the hyper parameters.

7. Discussion

In an IPM analysis, it is notoriously difficult to decide on the best definition of priors and observation errors, especially when changes in definitions appear to have contradictory outcome: an improved fit for one monitoring data set but a deteriorated fit for another. Having an accepted overall goodness-of-fit test for IPM would help, but such a test appears not to exist as yet. However, a similar approach as in Johnson et al. (2020) applying Chi-squared goodness-of-fit tests for the individual datasets could be adopted, possibly allowing for a more objective way to choose settings.

In the trial-and-error approach we followed, the coefficient of variation for the observation errors of counts and derogation offtake appeared to have a large impact on the results of the IPM. Besides the default settings, leading to the results in section 6.1, we tested the impact of alternative priors for the CV of these observation errors in two additional analyses. To see whether the prior for the CV of the derogation offtake observation error had a large influence on the results, the model was re-run with different values for this CV. The results in Appendix A Different priors for the CV of the derogation offtake reveal that this prior only has an impact on the fitted derogation numbers and the derogation offtake rates, but not on survival and reproduction. In an additional analysis, see Appendix C Different coefficients of variation for observation errors, two alternative sets of values for the CV values were employed, see Table 7. The alternative setting with 5-10 and 5-20 for CV counts and CV derogation, respectively, gave an improved fit for the January and derogation counts, and therefore a scenario analysis for this setting was also performed, see Figure 37. This reveals that, given the large uncertainty, there is hardly any difference with the scenario analysis for the default setting 5-20 / 5-40 (Figure 19).

The IPM assumes that juveniles are twice as vulnerable to derogation offtake than adults, i.e. $\rho = 2$. As this assumption is not backed up by much evidence, the results were compared to a JAGS run without a difference in vulnerability, i.e. $\rho = 1$, see Appendix B Differential vulnerability to derogation offtake of juveniles. The differences are minor, only the estimated derogation offtake rates (h) are slightly higher in both regions and periods, compensating for relatively lower offtake for juveniles.

The monitoring data with probably the highest uncertainty are the reported offtake numbers per region. For these both a bias from under- and overreporting seem to be possible. Underreporting or overreporting would mean that the real offtake is systematically higher or lower than what is accounted for in the IPM. Both directions of the bias could have consequences for the estimated demographic rates and thus for the scenarios. To test this, an additional analysis was performed assuming a bias of 0.5 (underreporting) and 2.0 (overreporting), see Appendix D Bias in reported derogation offtake. The results show minor differences in the mean of the posteriors of the January counts (Figure 38). The posteriors of the hyperparameters are very similar for survival and reproduction but not for the CV of the derogation error, which is a direct consequence of the bias parameter (Figure 39). The main impact of the bias parameter is in changing the fitted derogation offtake rate such that the fitted derogation with bias=0.5 is twice as large and the fitted derogation with bias=2.0 is half of the original fitted derogation. This seems to imply that for the current relatively low derogation rates (around 1 to 3%) a considerable bias in the observed derogation offtake (doubling or halving it) only has a minor effect on the posteriors of the demographic rates and thus also a minor effect on the outcome of any scenario analysis.

Overall, these findings indicate that the actual size of the derogation may not be the biggest point of concern, but rather the context in which this derogation offtake takes place: the current demographic rates of the MU1 population. A few “bad” years with low survival and/or reproduction will have a much larger impact on the arctic population than the limited derogation rates which have been reported thus far. However, if demographic coefficients stay what they appear to be from the analysis, any derogation offtake may (slightly) increase the risk of having a declining population, as shown by the scenarios. Whether this constellation of demographic rates is somewhat coincidentally caused by the few recent years in which the counts appear to level off, or whether this levelling off and the consequences it has on the estimated demographic rates is real, can only be concluded after data have become available for additional years.

8. Conclusions

The results obtained for the Russian population so far

- suggest that the population might be levelling off at around 1 million birds. However, this stabilization, if any, appears to be only in the few recent years. More data in future years will be needed to draw a definite conclusion.
- show a considerable year-to-year variation in demographic rates. There is some indication that, during the last decade, reproduction stabilizes at a somewhat lower level, adult natural survival is slightly larger and juvenile survival slightly lower.
- show that maintaining the estimated current derogation offtake rates with the current estimates of demographic rates implies some risk of a declining MU1 population in the near future.

9. Acknowledgements

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Appendix A Different priors for the CV of the derogation offtake

Figure 18 reveals that the posterior for the coefficient of variation of the observation error distribution for the derogation offtake is considerably shifted to the right as compared to the prior. Therefore different gamma hyperpriors for this error were used to re-run the model. These priors were defined by 98% prediction interval in between (5%, MAX), where MAX was set to 20%, 30%, 40%, 50% and 100%.

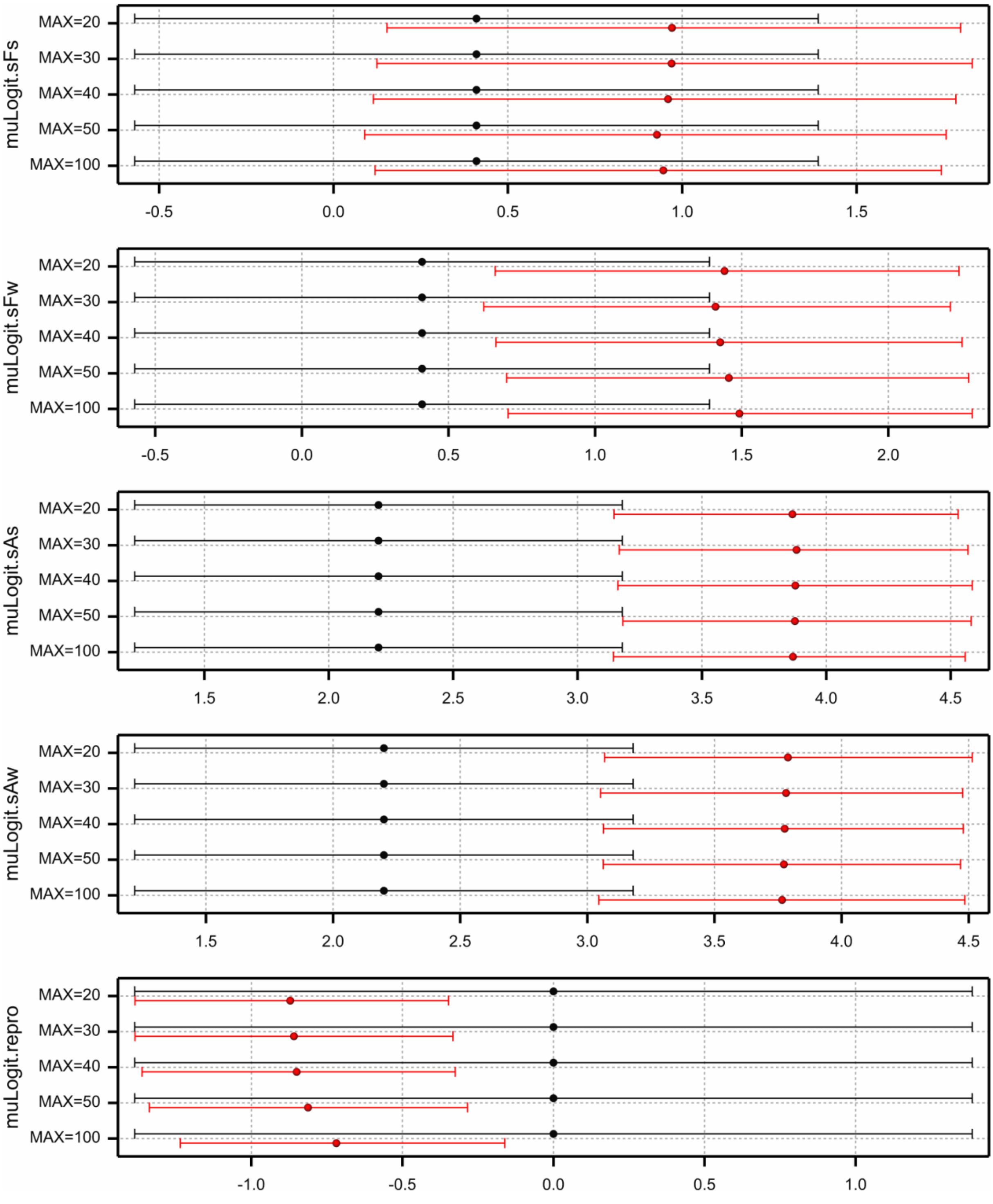

Figure 22: 95% intervals and means for priors (black) of the hyper parameters along with the 95% interval and means of the posterior (red) for different values of the upper 99% point (MAX) of the prediction interval of the gamma hyperprior for the error of reported derogation offtake.

The IPM model was re-run with the following number of MCMC runs: adapt=5,000, burnin=10,000, sample=15,000, thin=1 and chains=3. All parameters converged with psrf values in the interval (1.000, 1.03). Figure 22 reveals that the posteriors of the four survival parameters and the reproduction parameter do not depend on the value of MAX. Figure 23 shows that this also holds for the CV value of the observation error of the January counts and the dispersion parameter of the juvenile proportions, although the latter posterior is somewhat shifted to the left for MAX=100. The posterior for the CV value of the observation error for the derogation numbers is further shifted to the right when the MAX value increases. Posterior means for yearly January counts, the yearly proportion juveniles, the yearly reproduction and the yearly survival rates were hardly affected by the value of MAX. Only posterior means for derogation numbers, see Figure 24, and thus for derogation offtake rates were affected. A value of MAX=40% was more or less arbitrarily chosen for the model in the main text, since for larger values the fitted derogation numbers are (much) larger than the observed numbers.

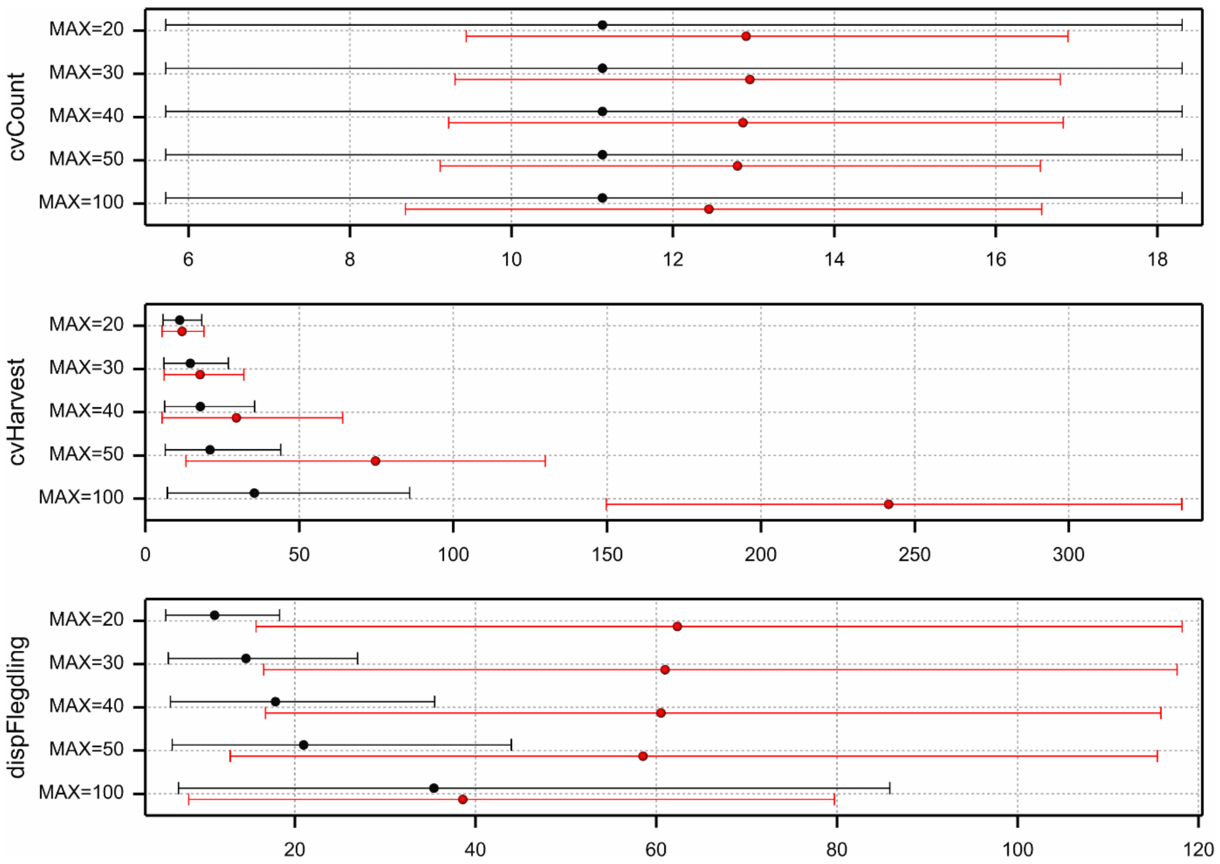

Figure 23: 95% intervals and means for priors (black) of the hyper parameters along with the 95% interval and means of the posterior (red) for different values of the upper 99% point (MAX) of the prediction interval of the gamma hyperprior for the observation error of derogation numbers.

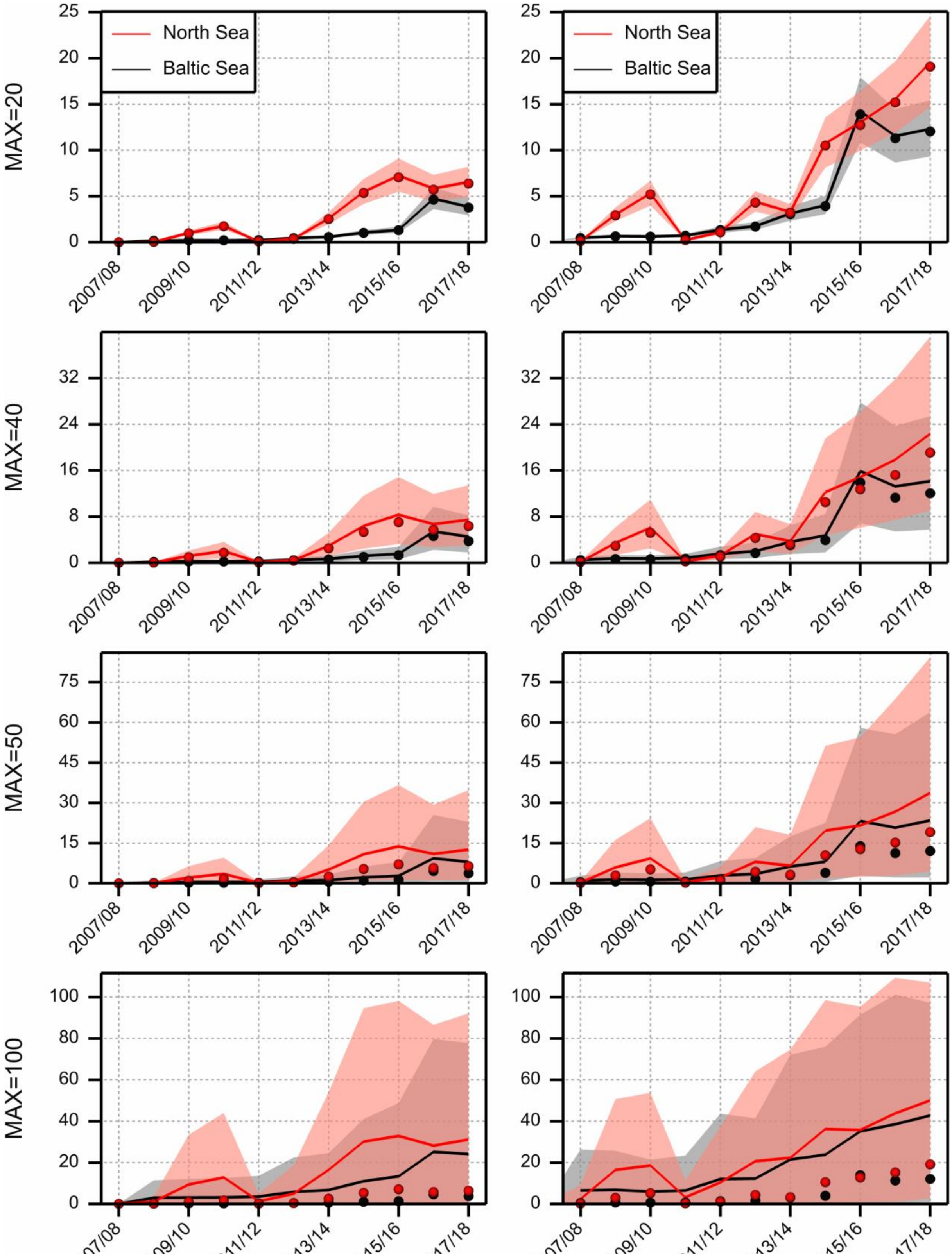

Figure 24: Observed derogation offtake numbers in the North Sea (red dots) and the Baltic Sea region (black dots) along with posterior means (lines) and posterior 95% intervals (areas) for different values of the upper 99% point (MAX) of the prediction interval of the gamma hyperprior for the observation error of derogation offtake. Left column: derogation offtake in period *s*; right column: derogation offtake in period *w*.

Appendix B Differential vulnerability to derogation offtake of juveniles

The IPM assumes that juveniles are twice as vulnerable to derogation offtake than adults, i.e. $\rho = 2$. The results were compared to a JAGS run without a difference in vulnerability, i.e. $\rho = 1$, employing the same number MCMC runs as for $\rho = 2$. Figure 25 displays the posteriors of the hyper parameters while Figure 26 compares the posterior means of the harvest rates. There are hardly any differences between the results for $\rho = 1$ and $\rho = 2$.

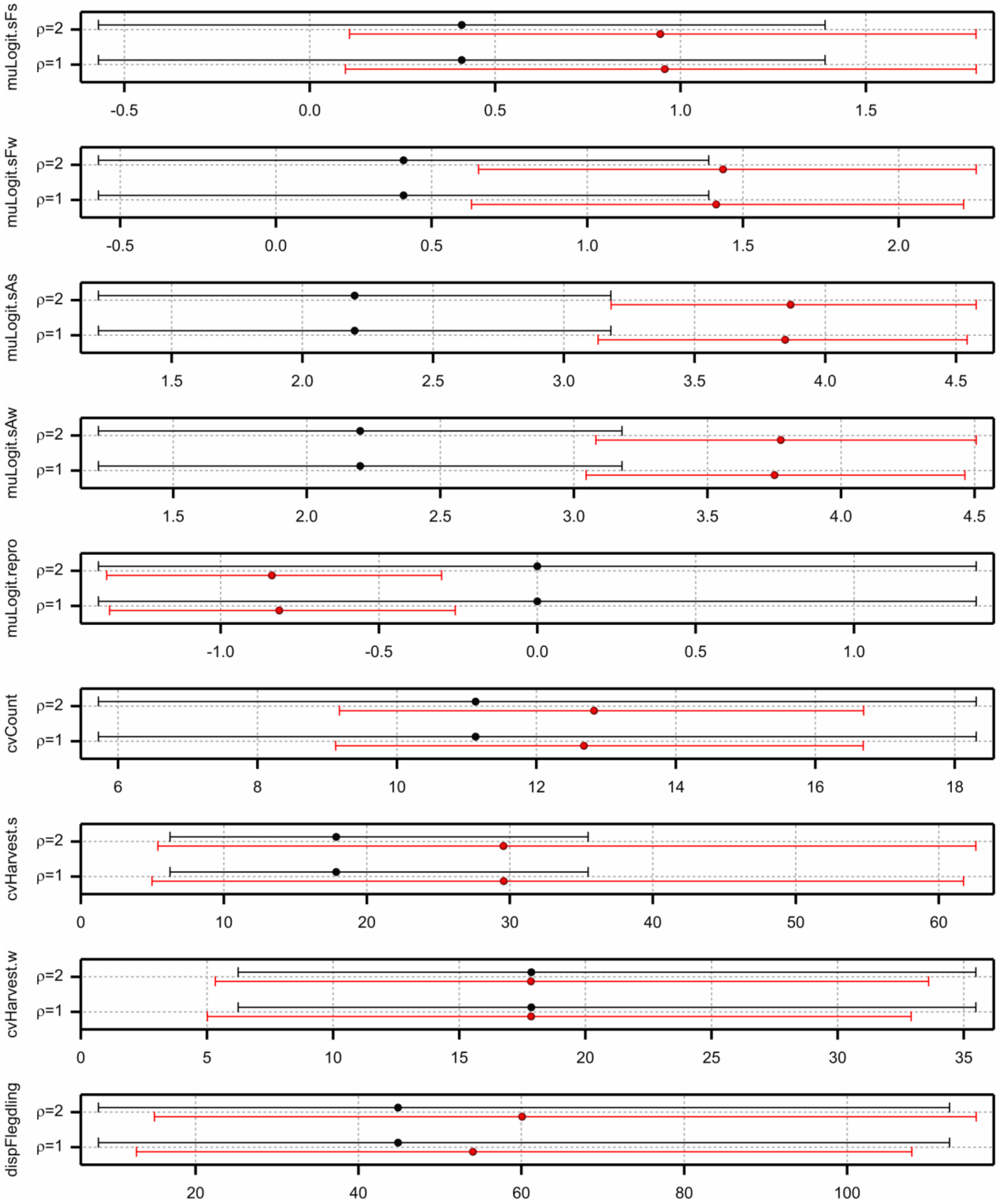

Figure 25: 95% intervals and means for priors (black) of the hyper parameters along with the 95% interval and means of the posterior (red) for the two values of the differential vulnerability (ρ) of juveniles to derogation offtake.

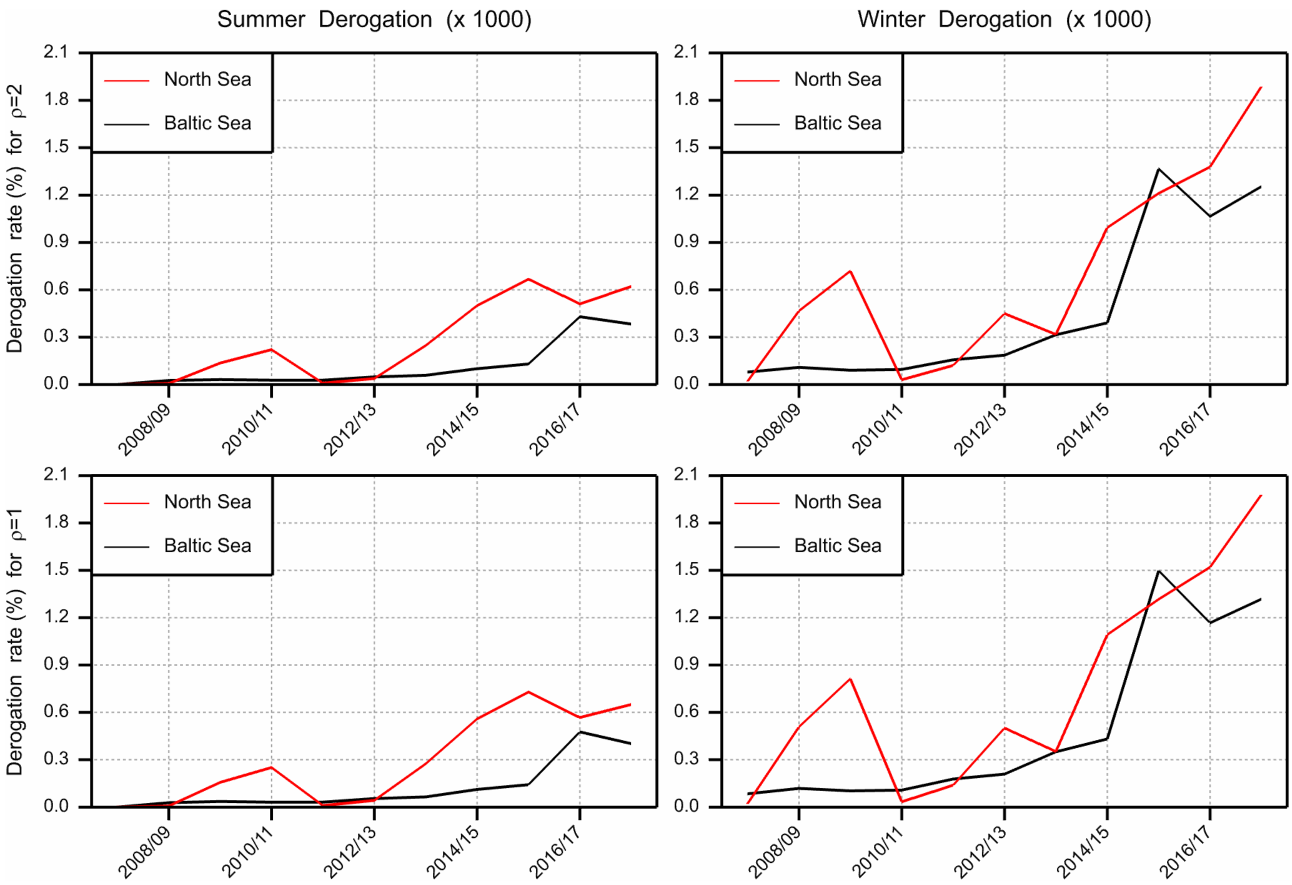

Figure 26: Posterior means and posterior 95% intervals for the derogation offtake rate in the North Sea and the Baltic Sea for the two values of the differential vulnerability (ρ) of juveniles to derogation offtake.

Appendix C Different coefficients of variation for observation errors

The coefficient of variation for the observation errors of counts and derogation offtake can possibly have a large impact on the results of the IPM. Therefore two alternative sets of values for the CV values were employed, see Table 7. In the figures below the results of the IPM are compared for these three sets.

Table 7: *Coefficients of variation for counts and derogation offtake which are compared in this Appendix. The interval defines the a 98% prediction interval for the respective priors*

	cvCount	cvDerogation
Main study	5 - 20	5 - 40
Alternative 1	1 - 5	5 - 20
Alternative 2	5 - 10	5 - 20

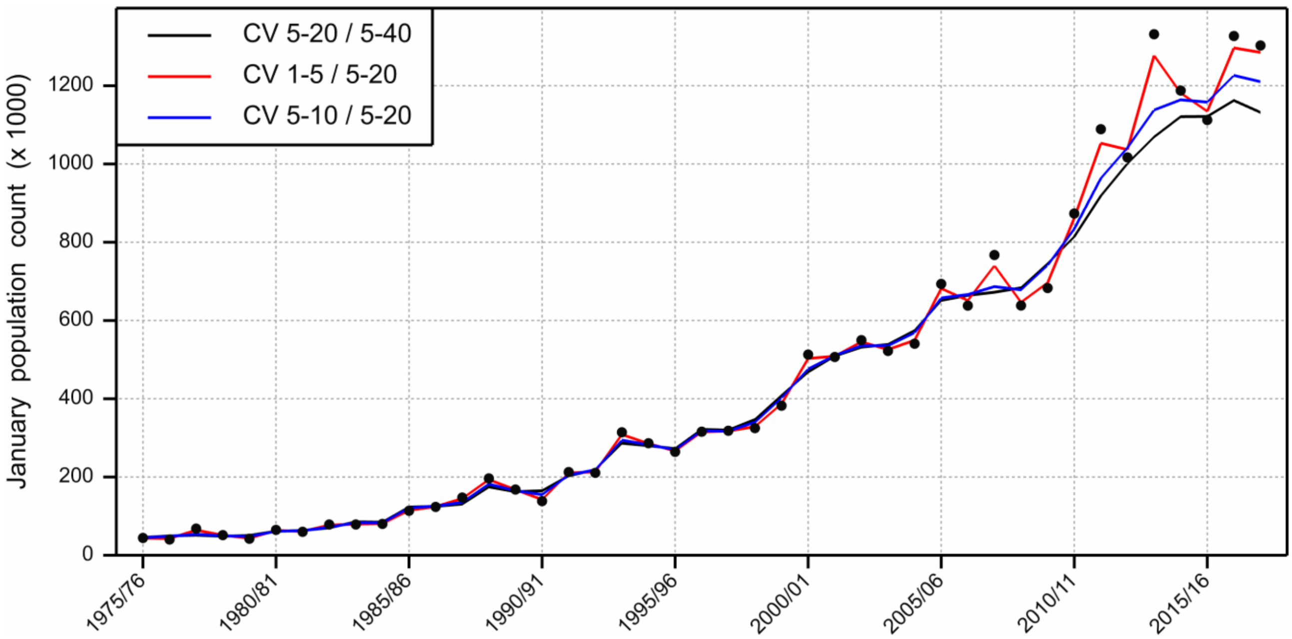

Figure 27: January total flyway population counts (black dots) and posterior means (lines) for the three sets of *CV* values.

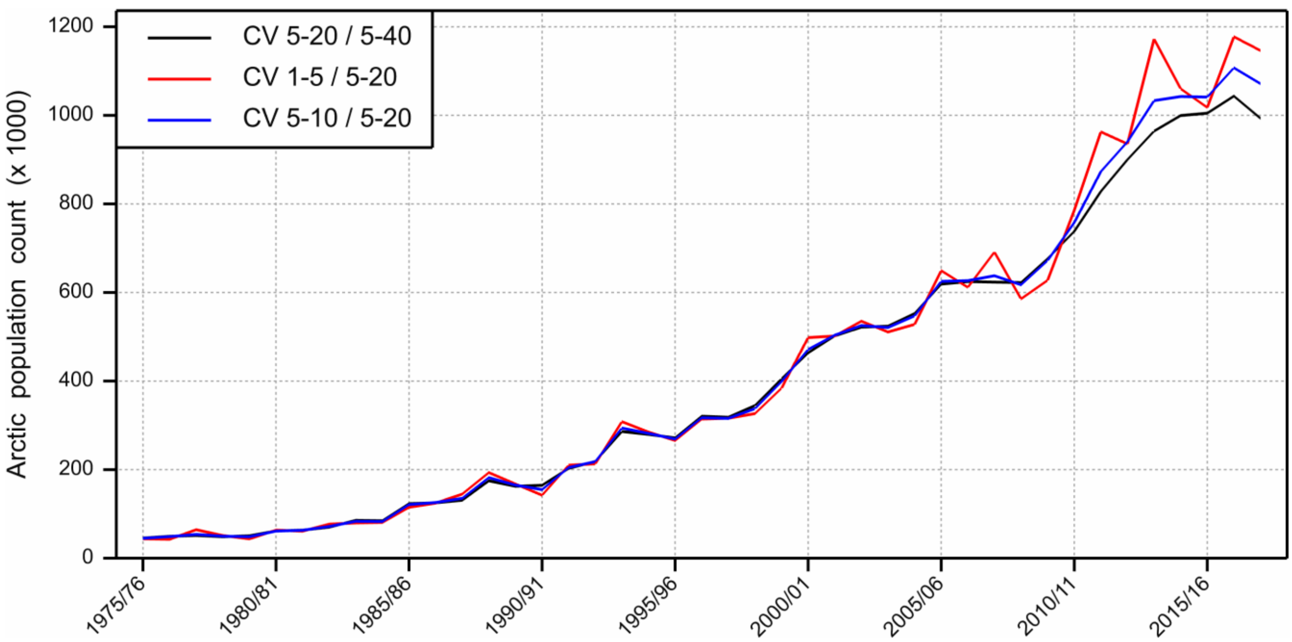

Figure 28: January Arctic population counts (black dots) and posterior means (lines)

The January counts in Figure 27 are followed very closely for the scenario with the smallest prior for the CV of the counts (1-5, red line). The more moderate values (5-10, blue line) seem to fit the counts better than the CV values used in the main study (5-20, black line) especially at the end of the observation period. The difference in mean posterior of the total flyway between the latter two settings is around 80,000 at the end of the observation period, with a similar difference for the Arctic population (Figure 28). Posterior means of the reproduction rate and natural survival are similar for the setting 5-20 / 5-40, as in the main study, and the setting 5-10 / 5-20, see Figure 30 to Figure 34, while the setting 1-5 / 5-20 give different results.

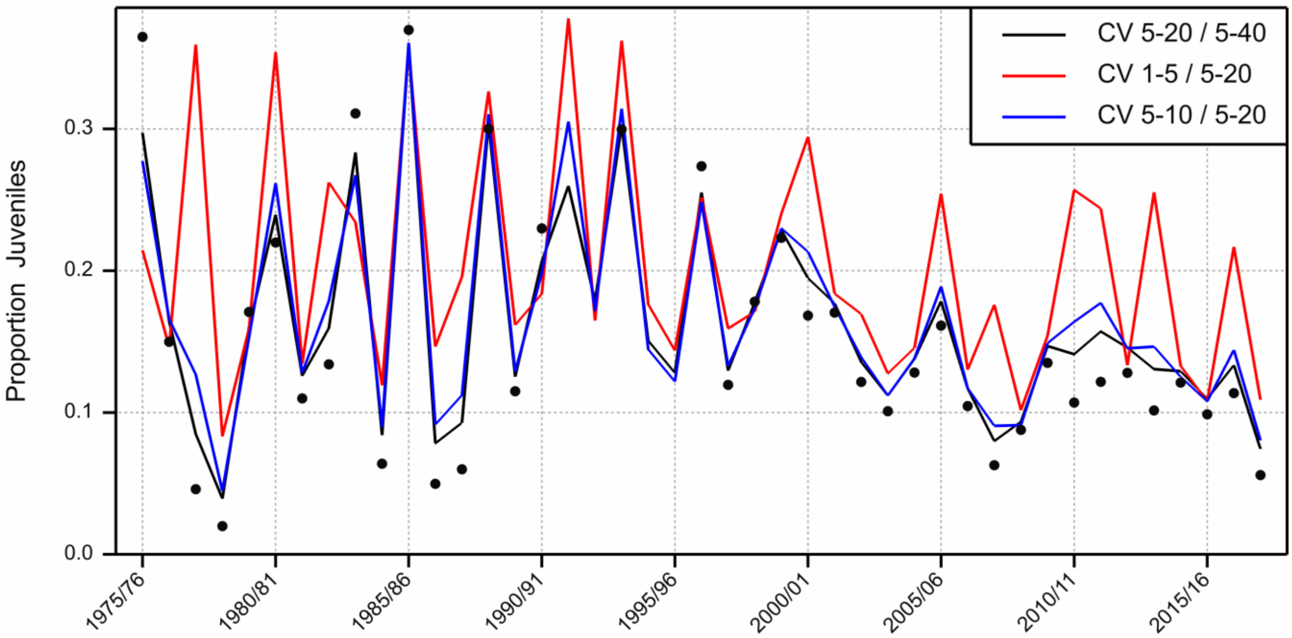

Figure 29: Observed proportion juveniles (dots) in the Netherlands and the German Dollard region in October to January, and posterior means (lines) for the three sets of *CV* values.

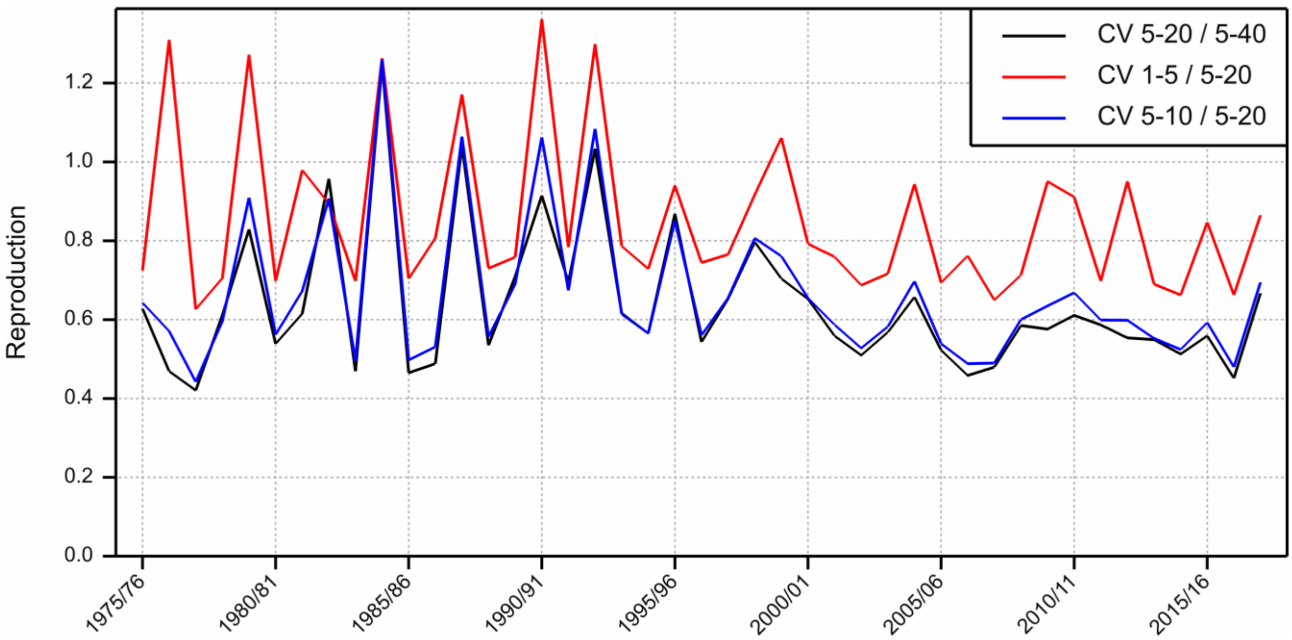

Figure 30: Posterior means for the reproduction rate of the MU1 population for the three sets of *CV* values.

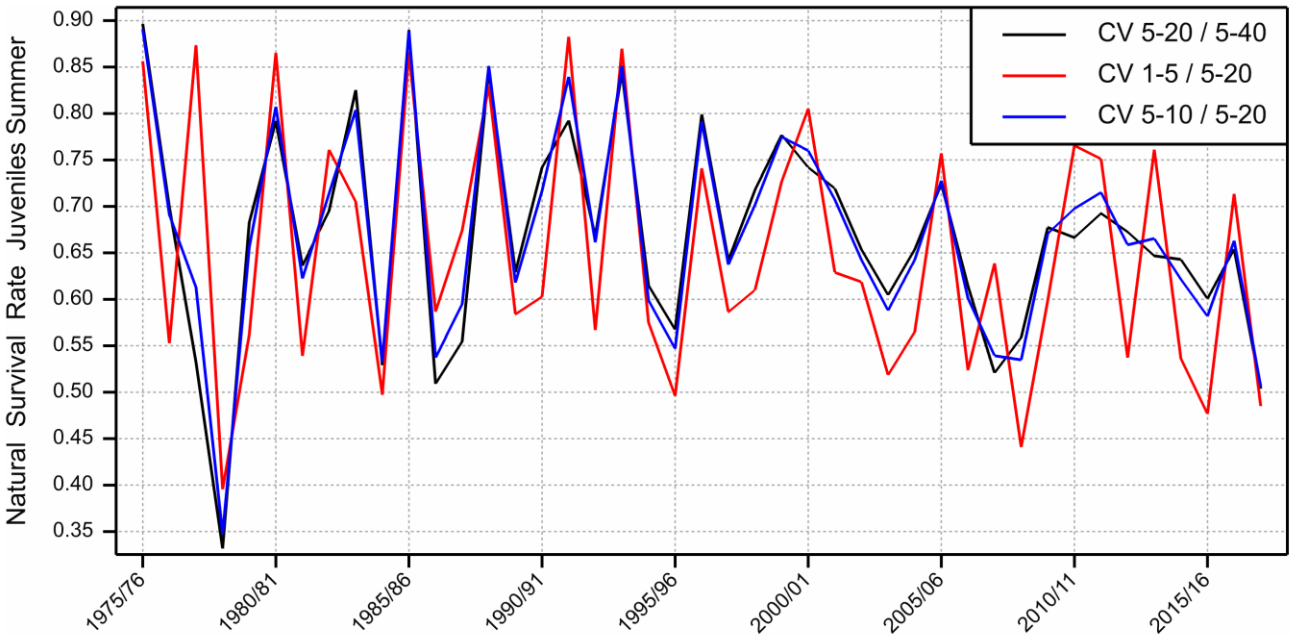

Figure 31: Posterior means for the natural survival (including unknown offtake in Russia) of juveniles in summer for the three sets of *CV* values.

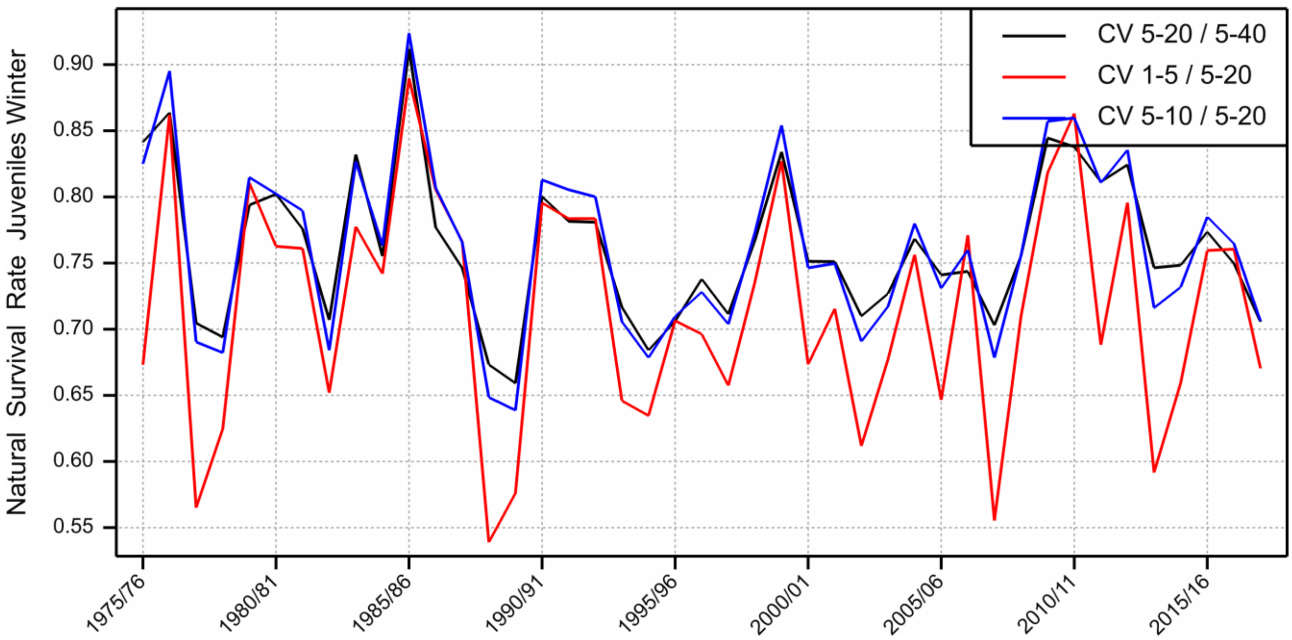

Figure 32: Posterior means for the natural survival (including unknown offtake in Russia) of juveniles in winter for the three sets of *CV* values.

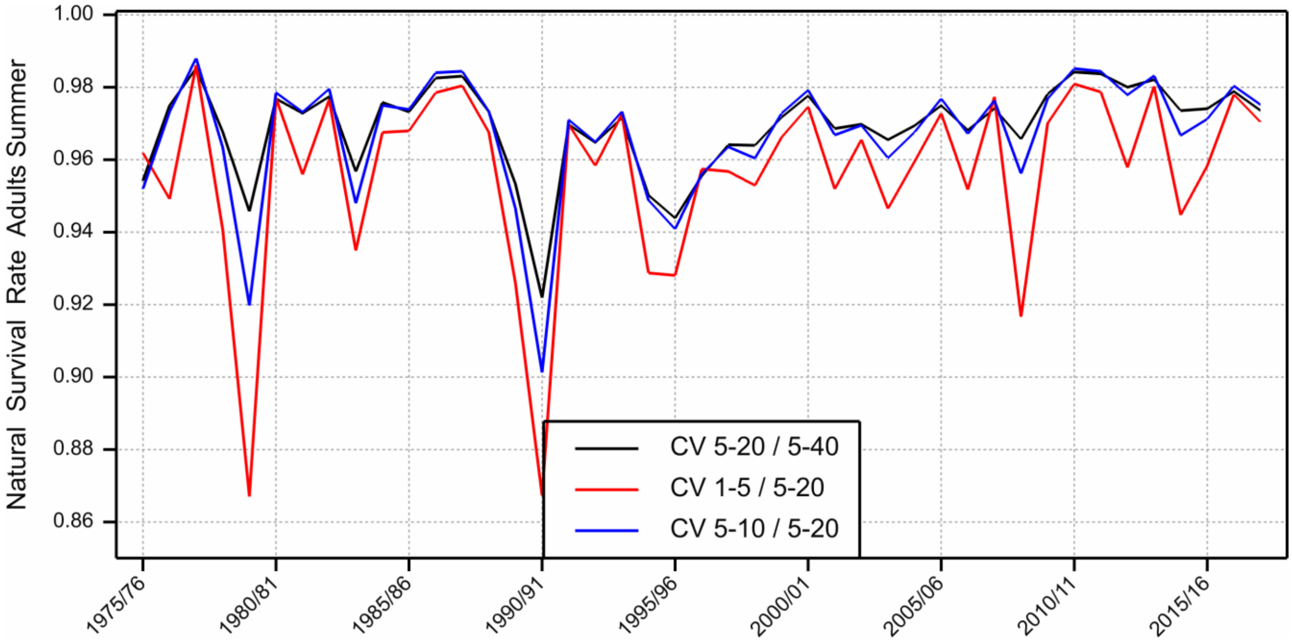

Figure 33: Posterior means for the natural survival (including unknown offtake in Russia) of adults in summer for the three sets of *CV* values.

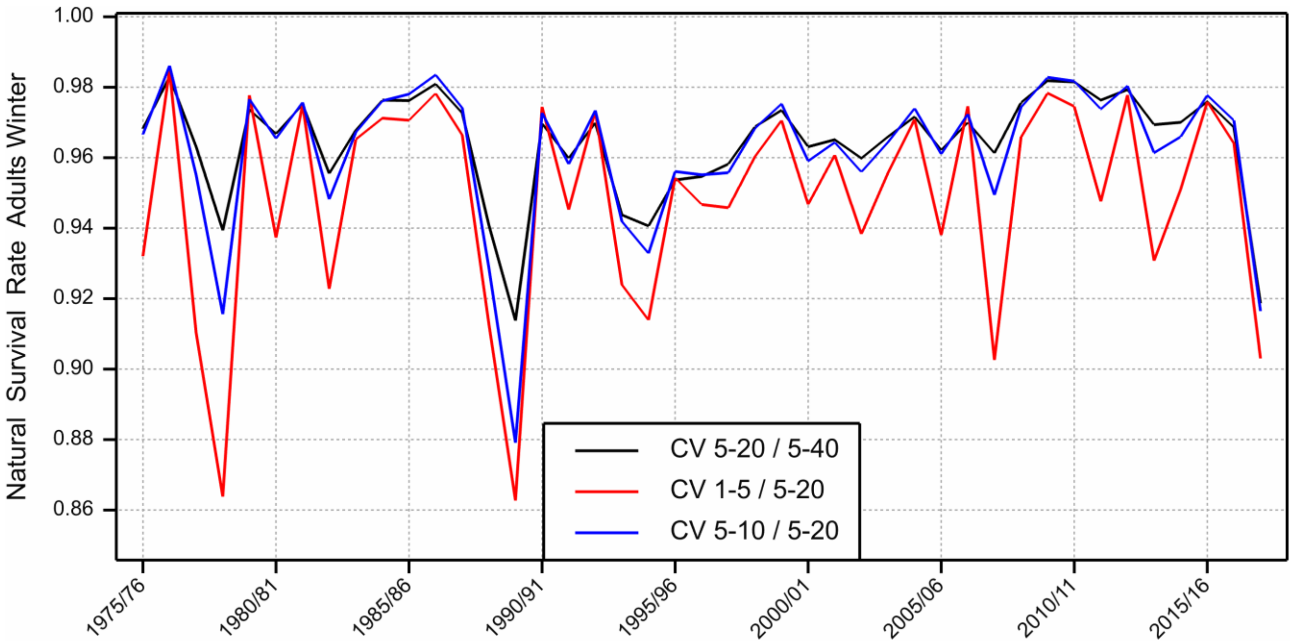

Figure 34: Posterior means for the natural survival (including unknown offtake in Russia) of adults in winter for the three sets of *CV* values.

Figure 35 again reveals that the posteriors for the hyperparameters are quite similar for the CV settings 5-20 / 5-40 and 5-10 / 5-20, off course excluding the CV hyperparameters, while the setting 1-5 / 5-20 gives different results.

Figure 36 shows that the narrower priors for the CV of the derogation observation error (middle and bottom panels) reproduce the observed derogation counts almost perfectly along with quite narrow 95% credible intervals.

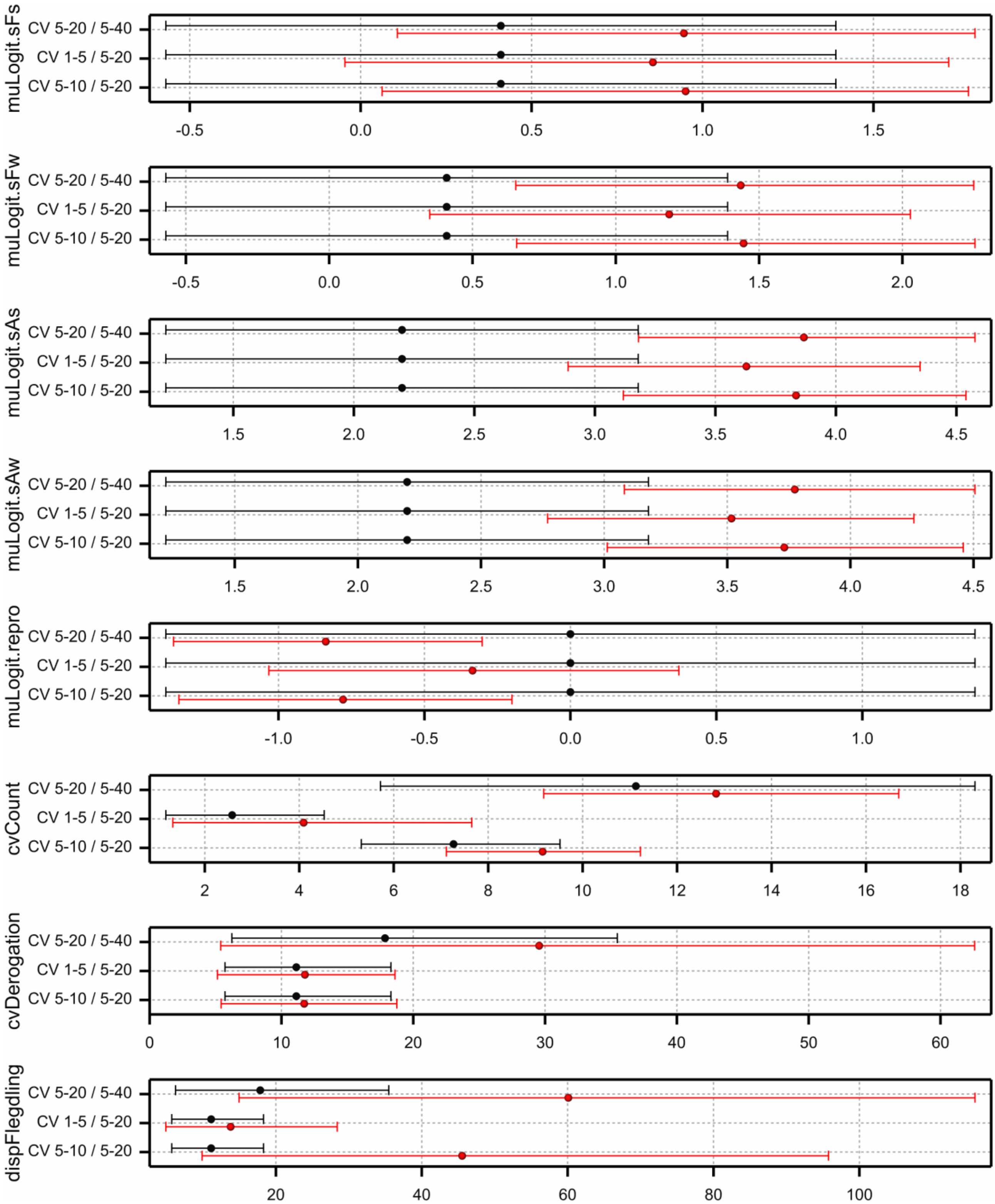

Figure 35: Posteriors of the hyperparameters for the three sets of *CV* values.

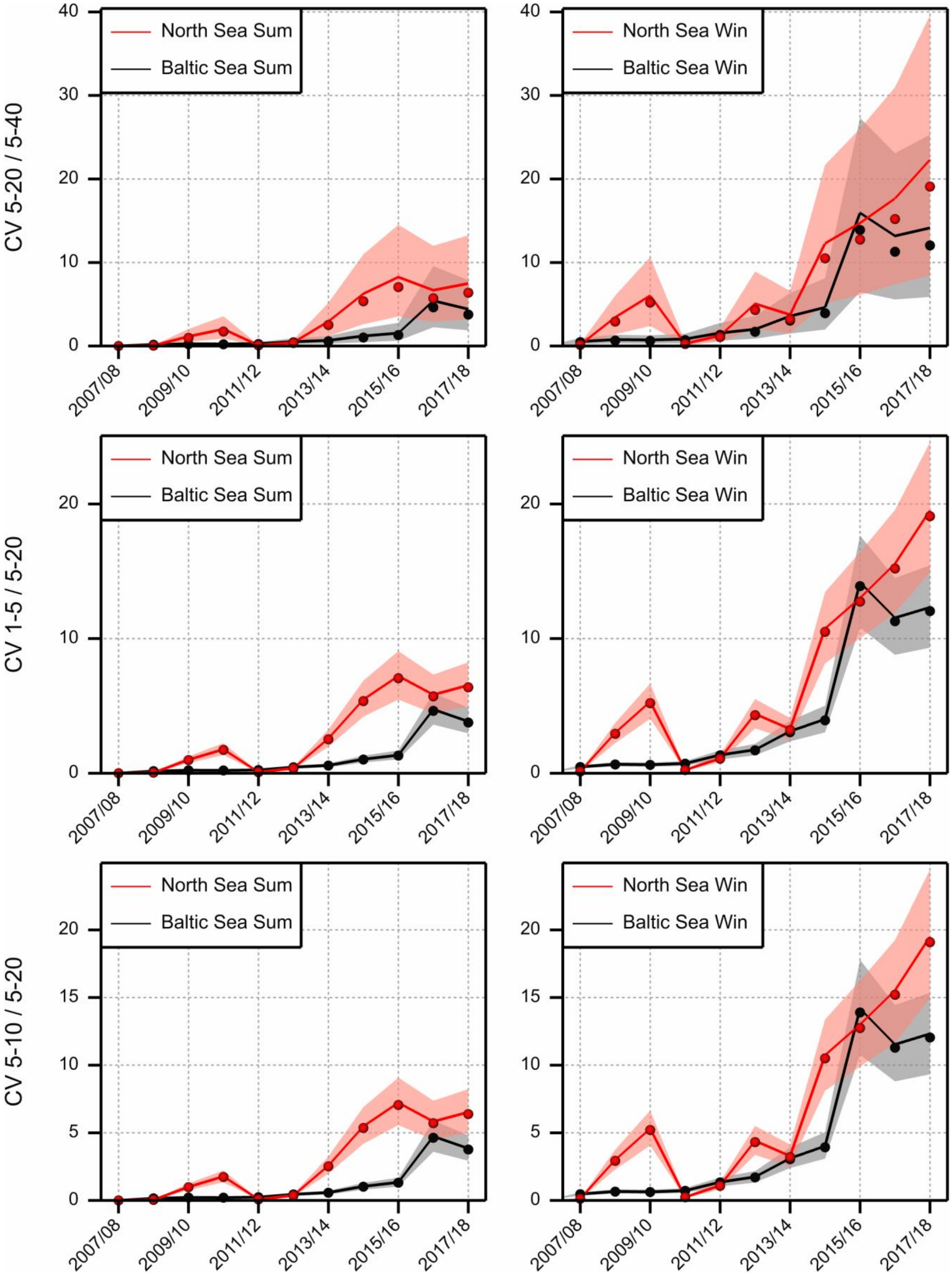

Figure 36: Observed derogation offtake in the North Sea (red dots) and the Baltic Sea (black dots) in period *s* ("summer") (left panels) and w ("winter") (right panels) for the three sets of *CV* values along with posterior means (lines) and posterior 95% intervals (areas).

It is concluded that the setting 1-5 / 5-20 for $CVcount$ and $CVderogation$ respectively gives a very good fit to both the January population counts and the derogation counts. However the narrow prior for $CVcount$ seems to be too informative given the smoothing spline analysis in section 5.5. The setting 5-10 / 5-20 is possibly more realistic and therefore a scenario analysis for this setting was performed, see Figure 37. This reveals that, given the large uncertainty, there is hardly any difference with the scenario analysis with the setting 5-20 / 5-40 in the main study, see Figure 19. This is rather comforting since it seems to imply that the specific priors for $CVcount$ and $CVderogation$ hardly have an effect on the scenario analysis as long as these CV values are not different from the values in the main study.

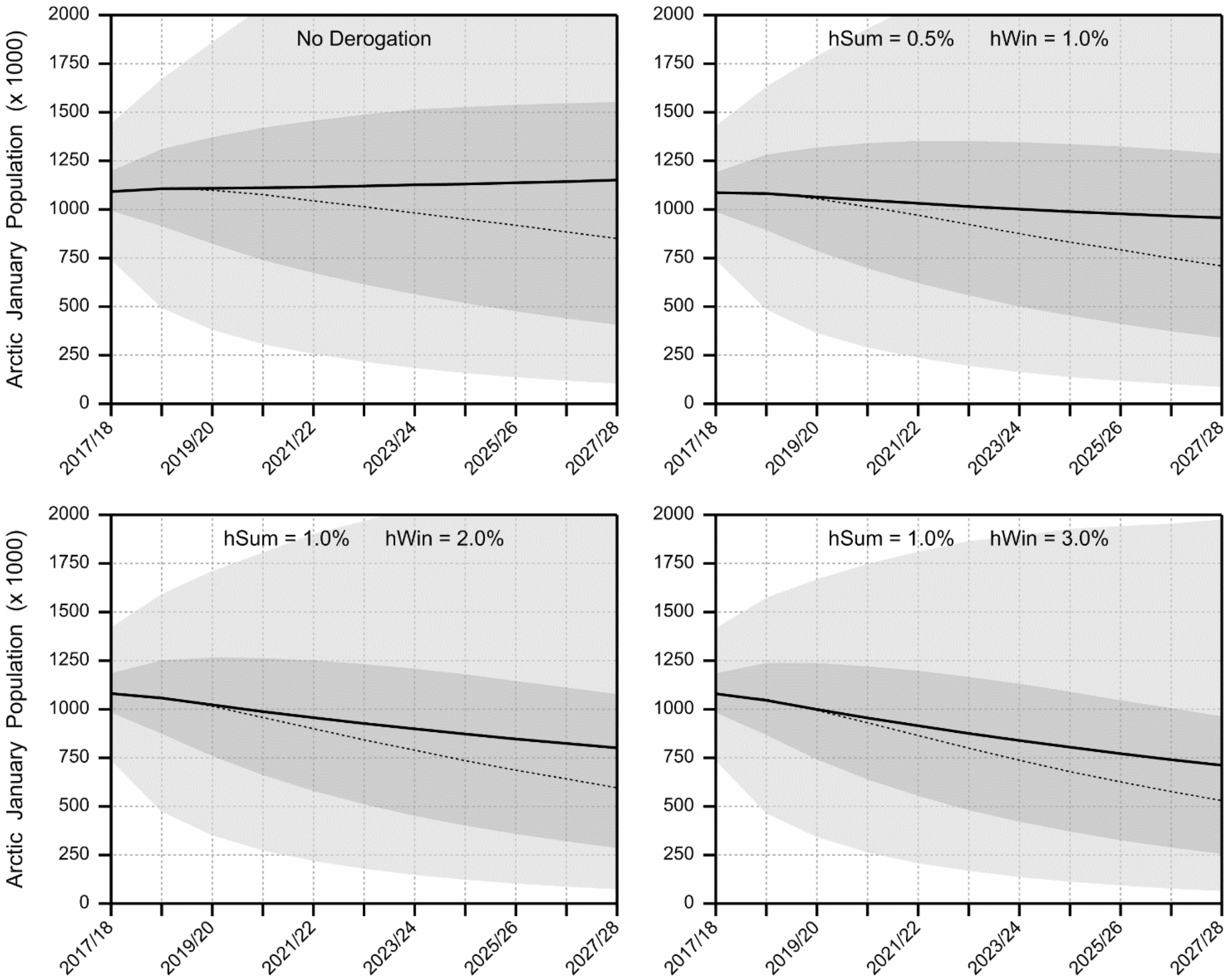

Figure 37: Scenario analysis for the CV setting 5-10 / 5-20 for January counts and derogation respectively. Mean (solid line), Median (dotted line), 50% central interval (grey) and 90% central interval (light grey) of 100,000 simulated future trajectories for MU1 for four derogation offtake scenarios, with different offtake percentages in period *s* (“Sum”) and *w* (“Win”).

Appendix D Bias in reported derogation offtake

In an additional analysis a fixed bias parameter for derogation offtake was added to the model. For example, for summer derogation in the Baltic Sea region, the following JAGS lines:

```
log.summerHarvest.BS[t] <- log(summerHarvest.BS[t])
hSummerBS[t] ~ dlnorm(log.summerHarvest.BS[t], log.tauHarvest.s)
```

were replaced by, employing the extra "bias" parameter:

```
log.summerHarvest.BS[t] <- log(bias * summerHarvest.BS[t])
hSummerBS[t] ~ dlnorm(log.summerHarvest.BS[t], log.tauHarvest.s)
```

The same modification was made for winter derogation in the Baltic and for winter and summer derogation in the North Sea region. Note that this modification is more or less similar to dividing the observed derogation counts by the bias parameter. The IPM was run again for bias=0.5 and for bias=2.0, and the results were compared with the original IPM run which basically employs bias=1. Figure 38 reveals that there is hardly any difference in the mean of the posteriors of the January counts for the different bias parameters. Only at the very end of the observation period, where indeed derogation was largest, there is a noticeable difference with the original IPM: bias=2.0 gives a final mean posterior which is around 20,000 larger and bias=0.5 gives a final mean posterior which is around 40,000 smaller than the original IPM run. Figure 39 shows that the posteriors of the hyperparameters are very similar indeed except for the CV of the derogation error which is a direct consequence of the value of the bias parameter. Finally, Figure 40 shows that the only impact of the added bias parameter is in changing the fitted derogation offtake rate such that the fitted derogation with bias=0.5 is twice as large and the fitted derogation with bias=2.0 is half of the original fitted derogation. This seems to imply that bias in the observed derogation offtake only has a minor effect on the posteriors of the demographic rates and thus also a minor effect on any scenario analysis.

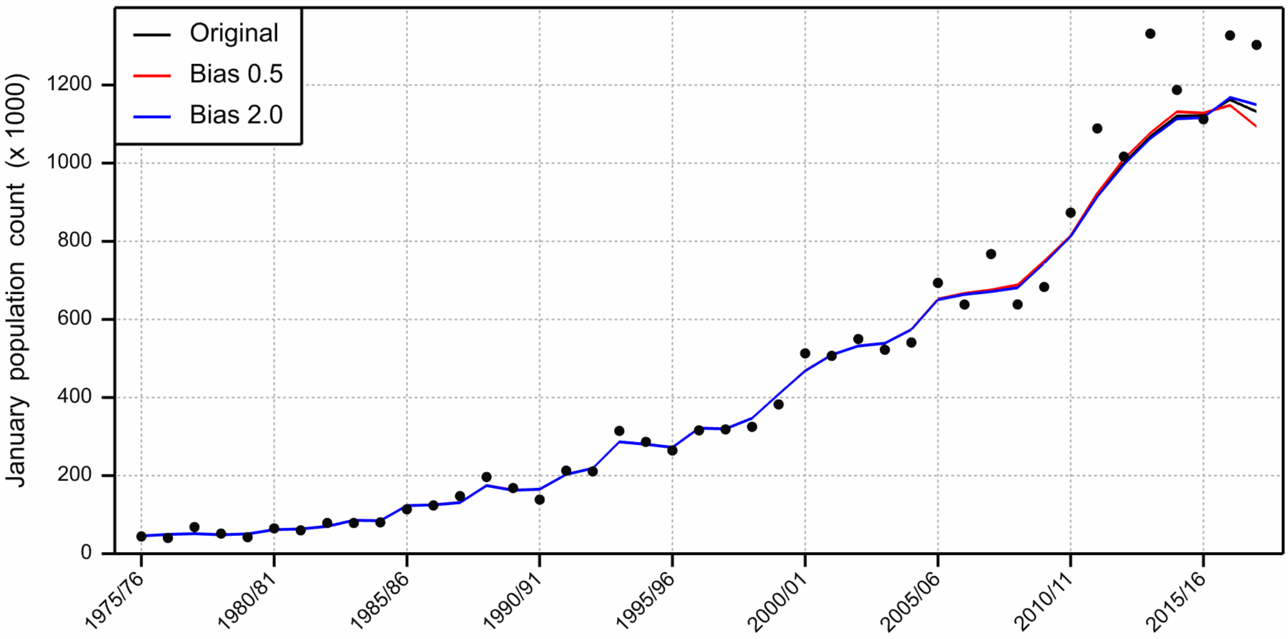

Figure 38: January total flyway population counts (black dots) and posterior means (lines) for the three values of the fixed bias parameter.

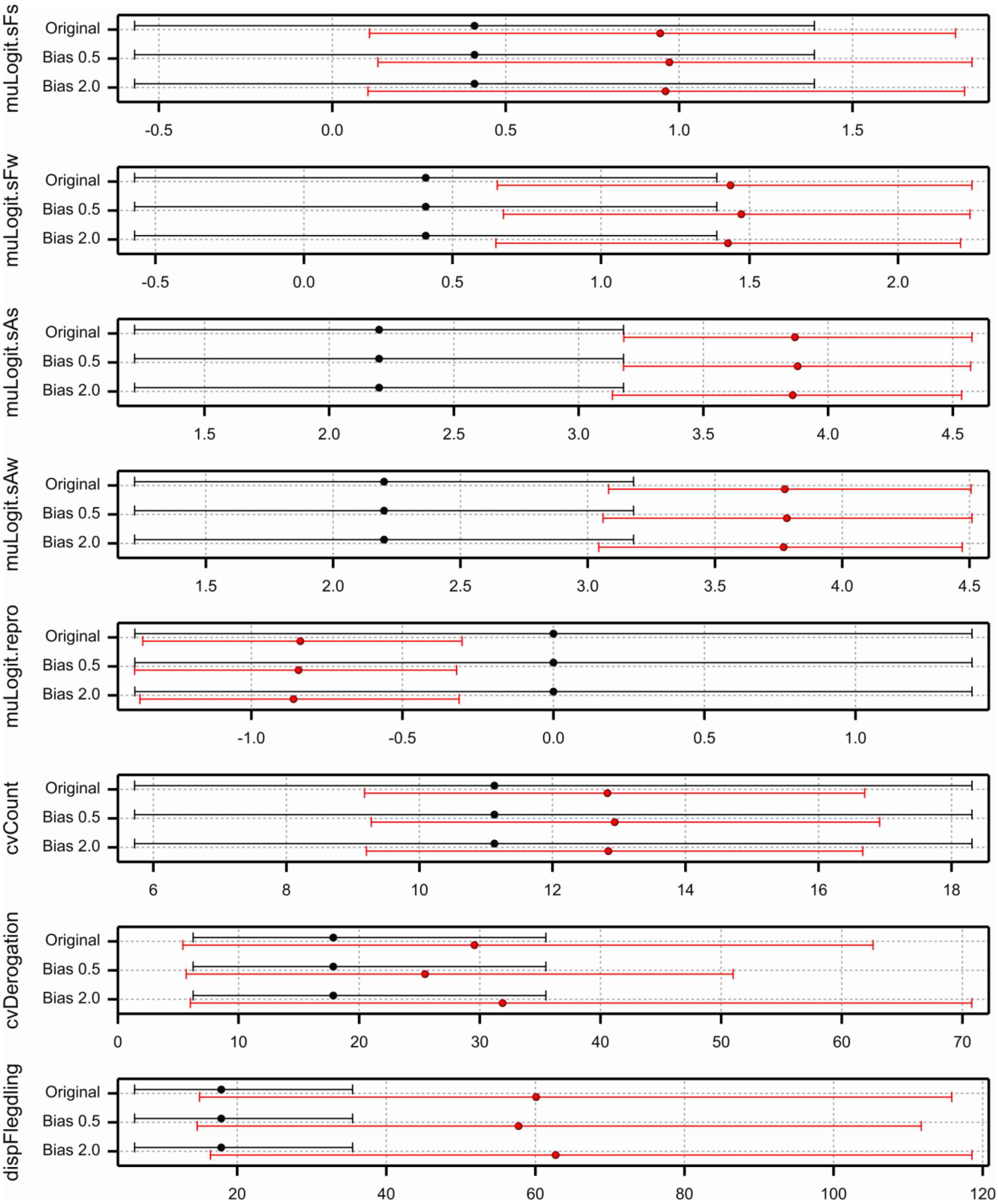

Figure 39: Posteriors of the hyperparameters for the three values of the fixed bias parameter.

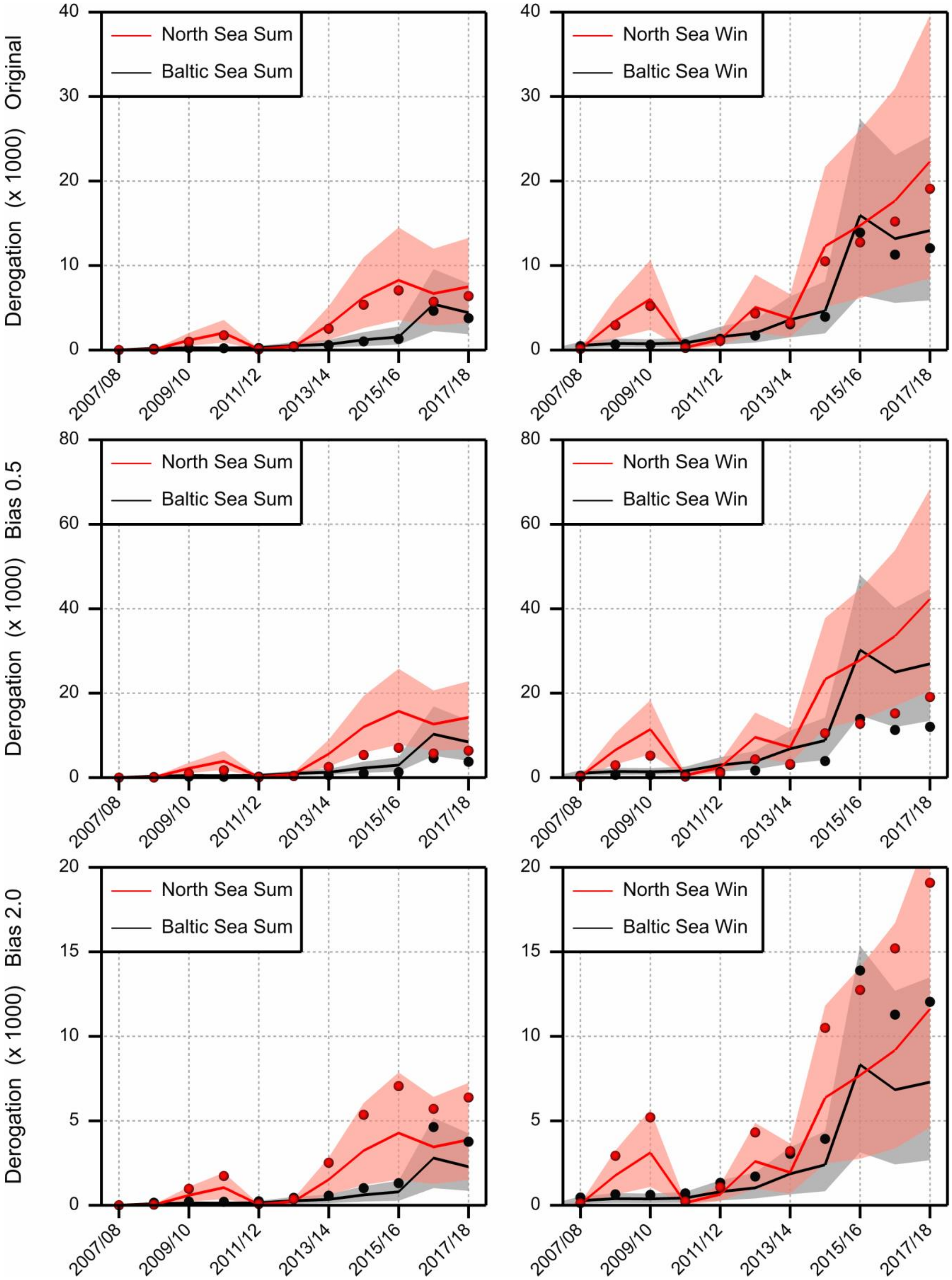

Figure 40: Observed derogation offtake in the North Sea (red dots) and the Baltic Sea (black dots) in period *s* ("summer") (left panels) and w ("winter") (right panels) for the three values of the fixed bias parameter along with posterior means (lines) and posterior 95% intervals (areas). Note that the y-axis range for bias=0.5 is twice the range for the original IPM run, while the y-axis range for bias=2.0 is half of the original range.

Appendix E IPM data input file

Table 8. The data input file used by the IPM. (Partly) imputed data is highlighted. The January counts were based on imputed values for Germany, in the last two years. The first part (before 2005) of the data for The Netherlands (NtNS1) was based on an assumed exponential growth model; same applies to Finish timeseries (NtBS1) before 2008. The whole Finnish timeseries was multiplied by 3.

Nr	Year	Season	Count	nFledgling	nGroup	hSummerBS	hWinterBS	hSummerNS	hWinterNS	NtNS1	NtBS1
1	1976	'1975/76'	44225	2184	5985	NA	NA	NA	NA	0	0
2	1977	'1976/77'	40349	897	5985	NA	NA	NA	NA	0	0
3	1978	'1977/78'	68172	275	5985	NA	NA	NA	NA	0	0
4	1979	'1978/79'	51488	119	5985	NA	NA	NA	NA	0	0
5	1980	'1979/80'	42249	1023	5985	NA	NA	NA	NA	0	0
6	1981	'1980/81'	64850	1867	8490	NA	NA	NA	NA	0	0
7	1982	'1981/82'	59928	950	8639	NA	NA	NA	NA	0	0
8	1983	'1982/83'	78623	999	7456	NA	NA	NA	NA	4	0
9	1984	'1983/84'	78733	1256	4040	NA	NA	NA	NA	6	0
10	1985	'1984/85'	80190	242	3787	NA	NA	NA	NA	9	0
11	1986	'1985/86'	113720	1295	3502	NA	NA	NA	NA	12	6
12	1987	'1986/87'	123633	132	2654	NA	NA	NA	NA	18	9
13	1988	'1987/88'	147627	126	2101	NA	NA	NA	NA	27	12
14	1989	'1988/89'	196423	600	2000	NA	NA	NA	NA	39	18
15	1990	'1989/90'	168022	345	3000	NA	NA	NA	NA	57	27
16	1991	'1990/91'	138393	330	1436	NA	NA	NA	NA	83	39
17	1992	'1991/92'	212685	NA	1	NA	NA	NA	NA	121	54
18	1993	'1992/93'	210632	NA	1	NA	NA	NA	NA	176	81
19	1994	'1993/94'	314367	608	2029	NA	NA	NA	NA	257	117
20	1995	'1994/95'	286347	NA	1	NA	NA	NA	NA	375	171
21	1996	'1995/96'	264426	NA	1	NA	NA	NA	NA	548	252
22	1997	'1996/97'	315793	3034	11086	NA	NA	NA	NA	800	366
23	1998	'1997/98'	318237	2352	19680	NA	NA	NA	NA	1168	534
24	1999	'1998/99'	324907	1511	8479	NA	NA	NA	NA	1705	780
25	2000	'1999/00'	382226	2143	9602	NA	NA	NA	NA	2489	1140
26	2001	'2000/01'	512952	131	778	NA	NA	NA	NA	3634	1665
27	2002	'2001/02'	506714	615	3608	NA	NA	NA	NA	5306	2433
28	2003	'2002/03'	549714	1091	8973	NA	NA	NA	NA	7747	3552
29	2004	'2003/04'	522164	3932	38955	NA	NA	NA	NA	11310	5184
30	2005	'2004/05'	540714	4719	36812	NA	NA	NA	NA	16513	7569
31	2006	'2005/06'	693423	4633	28722	NA	NA	NA	NA	25000	11049
32	2007	'2006/07'	638002	555	5308	NA	NA	NA	NA	27825	16134
33	2008	'2007/08'	767316	156	2482	NA	461	NA	124	30650	23553
34	2009	'2008/09'	638243	1356	15453	154	649	41	2930	33475	34389
35	2010	'2009/10'	682982	3585	26551	216	619	977	5206	36300	40344
36	2011	'2010/11'	873288	2238	20912	206	708	1735	234	41600	43161
37	2012	'2011/12'	1088846	2773	22795	236	1330	78	1074	46900	53484
38	2013	'2012/13'	1016746	3681	28764	443	1703	362	4312	52200	60258
39	2014	'2013/14'	1331560	2929	28866	568	3047	2520	3206	51573	65022
40	2015	'2014/15'	1187499	2543	20995	1016	3929	5358	10503	57276	78270
41	2016	'2015/16'	1112357	2566	25992	1310	13897	7056	12745	55558	74991
42	2017	'2016/17'	1326989	3326	29257	4632	11289	5710	15204	47653	85422
43	2018	'2017/18'	1302768	1703	30468	3763	12044	6383	19090	59844	95505

Appendix E R/JAGS code

```
## IPM for barnacle geese of the Russian management unit
Rprogram = "JAGS-Final"
intervalCVcounts <- c(5, 20)
intervalCVharvest <- c(5, 40)
coverageProb <- 0.98
## Fixed value for relative sensitivity of Fledglings to Derogation offtake
rho <- 2.0
## Fixed value for summer period survival of NS and BS birds (average)
phi <- 0.9

options(width=120)
source("../.Rutils/gamma.parms.from.quantiles.R")
seed   <- 8438381
set.seed(seed)

## Prior parameters for initial population size: LogNormal
## Initial population size is for the year before the first count (44225)
## CV value of Fledglings/Adults is 50%/20%
initPop    <- 40000
initPopF   <- 0.15*initPop
initPopA   <- initPop - initPopF
tauInit.nF  <- 1/log((50/100)^2 + 1)
tauInit.nA  <- 1/log((20/100)^2 + 1)
muInit.nF <- log(initPopF)
muInit.nA <- log(initPopA)
cbind(muInit.nF, tauInit.nF, muInit.nA, tauInit.nA)

## Prior parameters for survival: Logistic-Normal
mu.sFs <- 0.41;  tau.sFs <- 4;  sigma.sFs <- 4
mu.sFw <- 0.41;  tau.sFw <- 4;  sigma.sFw <- 4
mu.sAs <- 2.20;  tau.sAs <- 4;  sigma.sAs <- 4
mu.sAw <- 2.20;  tau.sAw <- 4;  sigma.sAw <- 4

## Prior parameters for Reproduction: Logistic-Normal multiplied by 2
mu.repro <- 0;  tau.repro <- 2;  sigma.repro <- 2

## Prior parameters for proportion Fledglings
shapeFlegdling <- 2.6635;  rateFlegdling <- 0.059374

## Prior parameters for derogation Rates
hrateLower <- 0.00;  hrateUpper <- 0.10

## Process error for January counts: LogNormal.
## The %CV value is with probability coverageProb in intervalCVcounts
quantiles <- c((1-coverageProb)/2, (1+coverageProb)/2)
parms <- gamma.parms.from.quantiles(intervalCVcounts/100, quantiles)
shapeCount <- parms$shape
scaleCount <- parms$scale
rateCount <- 1/scaleCount
print(cbind(shapeCount, scaleCount, rateCount))
cvCount <- rgamma(100000, shape=shapeCount, scale=scaleCount)
meanCV <- mean(cvCount); sdCV <- sd(cvCount); cvCV <- 100*sdCV/meanCV
qqCV <- quantile(100*cvCount, quantiles)
mean <- 100*shapeCount*scaleCount
q1 <- 100*qgamma(0.025, shape=shapeCount, scale=scaleCount)
q2 <- 100*qgamma(0.975, shape=shapeCount, scale=scaleCount)
cbind(meanCV, sdCV, cvCV, qq1=qqCV[1], qq2=qqCV[2], mean, q1, q2)

## Process error for derogation counts: LogNormal.
## The %CV value is with probability coverageProb in intervalCVharvest
quantiles <- c((1-coverageProb)/2, (1+coverageProb)/2)
parms <- gamma.parms.from.quantiles(intervalCVharvest/100, quantiles)
shapeHarvest <- parms$shape
scaleHarvest <- parms$scale
rateHarvest <- 1/scaleHarvest
print(cbind(shapeHarvest, scaleHarvest, rateHarvest))
```

```
cvHarvest <- rgamma(100000, shape=shapeHarvest, scale=scaleHarvest)
meanCV <- mean(cvHarvest); sdCV <- sd(cvHarvest); cvCV <- 100*sdCV/meanCV
qqCV <- quantile(100*cvHarvest, quantiles)
mean <- 100*shapeHarvest*scaleHarvest
q1 <- 100*qgamma(0.025, shape=shapeHarvest, scale=scaleHarvest)
q2 <- 100*qgamma(0.975, shape=shapeHarvest, scale=scaleHarvest)
cbind(meanCV, sdCV, cvCV, qq1=qqCV[1], qq2=qqCV[2], mean, q1, q2)

## Read data; REPLACE MISSING HARVEST WITH 1
data <- read.csv("Data_extended_2020_04_14.csv")
data$hSummerBS[is.na(data$hSummerBS)] = 1
data$hWinterBS[is.na(data$hWinterBS)] = 1
data$hSummerNS[is.na(data$hSummerNS)] = 1
data$hWinterNS[is.na(data$hWinterNS)] = 1
data$pFledgling = data$nFledgling/data$nGroup
N  <- nrow(data)
N1 <- N-1
startHunting = data[data$Year==2008, "Nr"]
startHunting1 = startHunting - 1
data[c(1:6, N - c(5:0)),]

## Combine structures to pass to JAGS in a list
JAGSinput <- list(N=N, N1=N1, startH1=startHunting1, startH=startHunting,
   Count=data$Count, NtBS1=data$NtBS1, NtNS1=data$NtNS1,
   hSummerBS=data$hSummerBS, hWinterBS=data$hWinterBS,
   hSummerNS=data$hSummerNS, hWinterNS=data$hWinterNS,
   nFledgling=data$nFledgling, nGroup=data$nGroup,
   muInit.nF=muInit.nF, tauInit.nF=tauInit.nF,
   muInit.nA=muInit.nA, tauInit.nA=tauInit.nA,
   mu.sFs=mu.sFs, tau.sFs=tau.sFs, sigma.sFs=sigma.sFs,
   mu.sFw=mu.sFw, tau.sFw=tau.sFw, sigma.sFw=sigma.sFw,
   mu.sAs=mu.sAs, tau.sAs=tau.sAs, sigma.sAs=sigma.sAs,
   mu.sAw=mu.sAw, tau.sAw=tau.sAw, sigma.sAw=sigma.sAw,
   mu.repro=mu.repro, tau.repro=tau.repro, sigma.repro=sigma.repro,
   shapeFlegdling=shapeFlegdling, rateFlegdling=rateFlegdling,
   shapeCount=shapeCount, rateCount=rateCount,
   shapeHarvest=shapeHarvest, rateHarvest=rateHarvest,
   hrateLower=hrateLower, hrateUpper=hrateUpper,
   rho=rho, phi=phi)
save(JAGSinput, file=paste0(Rprogram, "-Input.RData"))

## Define the JAGS model
JAGSmodel <- "model
{
  ## Priors for initial population size in July, just after reproduction
  nF[1] ~ dlnorm(muInit.nF, tauInit.nF)   # prior for initial number of Fledglings
  nA[1] ~ dlnorm(muInit.nA, tauInit.nA)   # prior for initial number of Adults

  ## Hyper-prior Logit-Normal for Survival Fledgling/Adult and Summer/Winter
  muLogit.sFs ~ dnorm(mu.sFs, tau.sFs)
  muLogit.sFw ~ dnorm(mu.sFw, tau.sFw)
  muLogit.sAs ~ dnorm(mu.sAs, tau.sAs)
  muLogit.sAw ~ dnorm(mu.sAw, tau.sAw)

  ## Hyper-prior for Beta-Binomial dispersion for proportion of Fledglings
  dispFlegdling ~ dgamma(shapeFlegdling, rateFlegdling)

  ## Survival for years WITHOUT hunting
  for (t in 1:startH1) {
    logit.theta.sFs[t] ~ dnorm(muLogit.sFs, 4/(sigma.sFs*sigma.sFs))   # Fledgling summer
    logit.theta.sFw[t] ~ dnorm(muLogit.sFw, 4/(sigma.sFw*sigma.sFw))   # Fledgling winter
    logit.theta.sAs[t] ~ dnorm(muLogit.sAs, 4/(sigma.sAs*sigma.sAs))   # Adult summer
    logit.theta.sAw[t] ~ dnorm(muLogit.sAw, 4/(sigma.sAw*sigma.sAw))   # Adult winter
    logit(theta.sFs[t]) <- logit.theta.sFs[t]
    logit(theta.sFw[t]) <- logit.theta.sFw[t]
    logit(theta.sAs[t]) <- logit.theta.sAs[t]
    logit(theta.sAw[t]) <- logit.theta.sAw[t]
    lambda.sFs[t] <- theta.sFs[t]
    lambda.sFw[t] <- theta.sFw[t]
    lambda.sAs[t] <- theta.sAs[t]
```

```
  lambda.sAw[t] <- theta.sAw[t]
}

## Survival for years WITH hunting
for (t in startH:N) {
  hRate.s.BS[t] ~ dunif(hrateLower, hrateUpper)
  hRate.w.BS[t] ~ dunif(hrateLower, hrateUpper)
  hRate.s.NS[t] ~ dunif(hrateLower, hrateUpper)
  hRate.w.NS[t] ~ dunif(hrateLower, hrateUpper)
  hRate.s[t]   <- hRate.s.BS[t] + hRate.s.NS[t]
  hRate.w[t]   <- hRate.w.BS[t] + hRate.w.NS[t]
}
for (t in startH:N) {
  logit.theta.sFs[t] ~ dnorm(muLogit.sFs, 4/(sigma.sFs*sigma.sFs))   # Fledgling summer
  logit.theta.sFw[t] ~ dnorm(muLogit.sFw, 4/(sigma.sFw*sigma.sFw))   # Fledgling winter
  logit.theta.sAs[t] ~ dnorm(muLogit.sAs, 4/(sigma.sAs*sigma.sAs))   # Adult summer
  logit.theta.sAw[t] ~ dnorm(muLogit.sAw, 4/(sigma.sAw*sigma.sAw))   # Adult winter
  logit(theta.sFs[t]) <- logit.theta.sFs[t]
  logit(theta.sFw[t]) <- logit.theta.sFw[t]
  logit(theta.sAs[t]) <- logit.theta.sAs[t]
  logit(theta.sAw[t]) <- logit.theta.sAw[t]
  lambda.sFs[t] <- (1-rho*hRate.s[t]) * theta.sFs[t]
  lambda.sFw[t] <- (1-rho*hRate.w[t]) * theta.sFw[t]
  lambda.sAs[t] <- (1-    hRate.s[t]) * theta.sAs[t]
  lambda.sAw[t] <- (1-    hRate.w[t]) * theta.sAw[t]
}

## Hyper-prior Logit-Normal for Reproduction
muLogit.repro ~ dnorm(mu.repro, tau.repro)
for (t in 1:N) {
  logit.Repro[t] ~ dnorm(muLogit.repro, 4/(sigma.repro*sigma.repro))   # Fledgling summer
  Repro[t] <- 2/(1+exp(-logit.Repro[t]))
}

## Hyper-prior for process error for January Count
cvCount ~ dgamma(shapeCount, rateCount)
log.tauCount <- 1/log(cvCount*cvCount + 1)

## Hyper-prior for process error for Derogation; indentical for BS and NS
cvHarvest ~ dgamma(shapeHarvest, rateHarvest)
log.tauHarvest <- 1/log(cvHarvest*cvHarvest + 1)

## IPM Population dynamics for July
for (t in 1:N1) {
  nA[t+1] <- max(1000, lambda.sAs[t]*lambda.sAw[t]*nA[t] + lambda.sFs[t]*lambda.sFw[t]*nF[t])
  nF[t+1] <- 0.5*Repro[t]*nA[t+1]
}

## Data: Counts in January
for (t in 1:N) {
  arcticCount[t] <- lambda.sAs[t]*nA[t] + lambda.sFs[t]*nF[t]
  januaryCount[t] <-arcticCount[t] + (1-hRate.s.NS[t])*phi*NtNS1[t] + (1-hRate.s[t])*phi*NtBS1[t]
  log.januaryCount[t] <- log(januaryCount[t])
  Count[t] ~ dlnorm(log.januaryCount[t], log.tauCount)
}

## Data: Fraction of fledglings in January; assumed to be identical in all three populations
for (t in 1:N) {
  pFledgling[t] <- lambda.sFs[t]*nF[t]/(lambda.sAs[t]*nA[t] + lambda.sFs[t]*nF[t])
  betaFledgling[t] ~ dbeta(dispFlegdling*pFledgling[t], dispFlegdling*(1-pFledgling[t]))
  nFledgling[t] ~ dbin(betaFledgling[t], nGroup[t])
}

## Data: derogation in Summer/Winter for 2008 - 2018
for (t in startH:N) {
  ## Summer Harvest
  summerTMP[t] <- rho*theta.sFs[t]*nF[t] + theta.sAs[t]*nA[t] + phi*NtBS1[t]
  summerHarvest.BS[t] <- hRate.s.BS[t]*summerTMP[t]
  summerHarvest.NS[t] <- hRate.s.NS[t]*(summerTMP[t] + phi*NtNS1[t])
  log.summerHarvest.BS[t] <- log(summerHarvest.BS[t])
```

```
    log.summerHarvest.NS[t] <- log(summerHarvest.NS[t])
    hSummerBS[t] ~ dlnorm(log.summerHarvest.BS[t], log.tauHarvest)
    hSummerNS[t] ~ dlnorm(log.summerHarvest.NS[t], log.tauHarvest)

    ## Winter derogation
    winterTMP[t] <- rho*(1-rho*hRate.s[t])*theta.sFs[t]*nF[t] +
      (1-rho*hRate.s[t]) * (theta.sAs[t]*nA[t] + phi*NtBS1[t])
    winterHarvest.BS[t] <- hRate.w.BS[t]*winterTMP[t]
    winterHarvest.NS[t] <- hRate.w.NS[t]*(winterTMP[t] + (1-hRate.s.NS[t])*phi*NtNS1[t])
    log.winterHarvest.BS[t] <- log(winterHarvest.BS[t])
    log.winterHarvest.NS[t] <- log(winterHarvest.NS[t])
    hWinterBS[t] ~ dlnorm(log.winterHarvest.BS[t], log.tauHarvest)
    hWinterNS[t] ~ dlnorm(log.winterHarvest.NS[t], log.tauHarvest)
  }

  ## Data: derogation in Summer/Winter for 1976 - 2007
  ## Redundant but necessary for monitoring
  for (t in 1:startH1) {
    hRate.s.BS[t] ~ dunif(0.0, 0.00001)
    hRate.w.BS[t] ~ dunif(0.0, 0.00001)
    hRate.s.NS[t] ~ dunif(0.0, 0.00001)
    hRate.w.NS[t] ~ dunif(0.0, 0.00001)
    hRate.s[t]   <- hRate.s.BS[t] + hRate.s.NS[t]
    hRate.w[t]   <- hRate.w.BS[t] + hRate.w.NS[t]
    summerTMP[t] <- rho*theta.sFs[t]*nF[t] + theta.sAs[t]*nA[t] + phi*NtBS1[t]
    summerHarvest.BS[t] <- hRate.s.BS[t]*summerTMP[t]
    summerHarvest.NS[t] <- hRate.s.NS[t]*(summerTMP[t] + phi*NtNS1[t])
    winterTMP[t] <- rho*(1-rho*hRate.s[t])*theta.sFs[t]*nF[t] +
      (1-rho*hRate.s[t]) * (theta.sAs[t]*nA[t] + phi*NtBS1[t])
    winterHarvest.BS[t] <- hRate.w.BS[t]*winterTMP[t]
    winterHarvest.NS[t] <- hRate.w.NS[t]*(winterTMP[t] + (1-hRate.s.NS[t])*phi*NtNS1[t])
  }
}
"

## Load JAGS libraries
library(coda)
library(rjags)
library(runjags)

## What to monitor
JAGSmonitor <- c("januaryCount", "arcticCount", "nF", "nA",
    "pFledgling", "betaFledgling", "Repro",
    "summerHarvest.BS", "winterHarvest.BS", "summerHarvest.NS", "winterHarvest.NS",
    "hRate.s.BS", "hRate.w.BS", "hRate.s.NS", "hRate.w.NS",
    "theta.sFs",  "theta.sFw",  "theta.sAs",  "theta.sAw",
    "lambda.sFs", "lambda.sFw", "lambda.sAs", "lambda.sAw",
    "muLogit.sFs", "muLogit.sFw", "muLogit.sAs", "muLogit.sAw", "dispFlegdling",
    "muLogit.repro", "cvCount", "cvHarvest")

## MCMC settings
source(".RunFinal.r")
test=TRUE
test=FALSE
if (test) {
  adapt <- 500;  burnin <- 1000;  sample <- 1000;  thin <- 1;  chains <- 3
}

## Set initial values
vNA <- rep(NA,N)
TMPinits <- list(
    nF=vNA, nA=vNA,
    muLogit.sFs=NA, muLogit.sFw=NA, muLogit.sAs=NA, muLogit.sAw=NA,
    muLogit.repro=NA ,dispFlegdling=NA, cvCount=NA, cvHarvest=NA,
    .RNG.seed=seed, .RNG.name="base::Wichmann-Hill")

## Inits; repeat for different chains
JAGSinits <- list()
initpopF  <-  6000
initpopA  <- 34000
```

```
initpopCV <-    10
initpopVAR <- log((initpopCV/100)^2 + 1)
initpopSD  <- sqrt(initpopVAR)
meanFledgling <- shapeFlegdling/rateFlegdling

c1 <- 0.5
for (ii in 1:chains) {
  TMPinits$nF[1] <- rlnorm(1, log(initpopF) - initpopVAR/2, initpopSD)
  TMPinits$nA[1] <- rlnorm(1, log(initpopA) - initpopVAR/2, initpopSD)
  TMPinits$muLogit.sFs <- runif(1, mu.sFs - c1, mu.sFs + c1)
  TMPinits$muLogit.sFw <- runif(1, mu.sFw - c1, mu.sFw + c1)
  TMPinits$muLogit.sAs <- runif(1, mu.sAs - c1, mu.sAs + c1)
  TMPinits$muLogit.sAw <- runif(1, mu.sAw - c1, mu.sAw + c1)
  TMPinits$muLogit.repro <- runif(1, mu.repro - c1, mu.repro + c1)
  TMPinits$dispFlegdling <- runif(1, meanFledgling-10, meanFledgling+10)
  TMPinits$cvCount <- rgamma(1, shape=shapeCount, rate=rateCount)
  TMPinits$cvHarvest <- rgamma(1, shape=shapeHarvest, rate=rateHarvest)
  TMPinits$.RNG.seed <- TMPinits$.RNG.seed + 1
  JAGSinits[[ii]] <-  TMPinits
}

## Run JAGS model
start_time = Sys.time()
runjags.options(force.summary=TRUE)
samples <- run.jags(model=JAGSmodel, data=JAGSinput, inits=JAGSinits, monitor=JAGSmonitor,
    n.chains=chains, adapt=adapt, burnin=burnin, sample=sample, thin=thin)
Sys.time()- start_time

## Save all results
## Save selected columns from summary for producing graphs.
## Note that colnames and rownames are written to separate files
save(samples, file=paste0(Rprogram, ".RData"))
attr(samples[[1]], "class") <- NULL
sumAllColumns <- summary(samples)
rownames(sumAllColumns) <- colnames(samples$mcmc[[1]])
selectCols <- c(4,1,2,3,11)
summary <- cbind(sumAllColumns[, selectCols])
summaryRows <- colnames(samples$mcmc[[1]])
summaryCols <- colnames(sumAllColumns)[selectCols]
save(summary, file=paste0(Rprogram, "-Summary.RData"))
save(summaryRows, file=paste0(Rprogram, "-SummaryRows.RData"))
save(summaryCols, file=paste0(Rprogram, "-SummaryCols.RData"))

##  January counts and fitted values
Nmean  <- as.numeric(summary[grepl("januaryCount", rownames(summary)), 'Mean'])
Nlow   <- as.numeric(summary[grepl("januaryCount", rownames(summary)), 'Lower95'])
Nupp   <- as.numeric(summary[grepl("januaryCount", rownames(summary)), 'Upper95'])
NFmean <- as.numeric(summary[grepl("nF", rownames(summary)), 'Mean'])
NFlow  <- as.numeric(summary[grepl("nF", rownames(summary)), 'Lower95'])
NFupp  <- as.numeric(summary[grepl("nF", rownames(summary)), 'Upper95'])
NAmean <- as.numeric(summary[grepl("nA", rownames(summary)), 'Mean'])
NAlow  <- as.numeric(summary[grepl("nA", rownames(summary)), 'Lower95'])
NAupp  <- as.numeric(summary[grepl("nA", rownames(summary)), 'Upper95'])
cbind(data[,c(2,4)], Nmean, Nlow, Nupp, NFmean, NFlow, NFupp, NAmean, NAlow, NAupp)
```

Annex 4. Impact Models

According to the ISSMPs for the Greylag Goose and the Barnacle Goose Range States are mandated to quantify the consequences of changes in population size on fundamental objectives, e.g., investigate if there is a relationship between goose abundances and the amount of damage caused by the species to agricultural crops, risks to air safety or other sensitive flora and fauna.

In order to scale up an assessment of the extent of damage or risks from local to regional, national or even flyway levels, it is necessary to apply either a retrospective time series, statistical analysis or a predictive simulation approach. With regard to agricultural damage, some first indicative examples of national time series analyses were provided in the respective ISSMPs based on compensation payments to farmers in relationship to annual abundances of geese. For Sweden this analysis has been extended and validated (Montràz-Janer et al. 2019). In case of Denmark, where compensation or subsidies are not used to support crop damage management, derogation has been used as a proxy of the intensity of crop loss. At national level, there was a relationship between Barnacle Goose numbers and licenses granted for derogation shooting (Clausen et al. 2020). In the Netherlands, retrospective analyses are also in progress (to be reported in 2021).

Predictive models to assess the relationship have so far been developed at regional levels in Norway (Baveco et al. 2017). Work is in progress in the Netherlands and Denmark (at regional level), using individual-based models and agent-based simulations, respectively (to be reported in 2021). The process of building, parameterisation and testing such models is resource demanding and cannot be rolled out easily to all Range States. Hence, at least for the foreseeable future, such models can realistically only be used for selected regions.

References

Baveco, H.M. et al. (2017). Combining modelling tools to evaluate a goose management scheme. *Ambio* 46(2): 210-223.

Clausen, K.C., Heldbjerg, H., Balsby, T., Clausen, P., Nielsen, R.D., Skov. F. & Madsen, J. (2020). *Sammenhæng mellem forekomst af bramgæs og reguleringsindsats i Danmark.* Scientific Report, Aarhus University, Denmark (in press).

Montràz-Janer, T., Knape, J., Nilsson, L., Tombre, I., Pärt, T. & Månsson, J. (2019). Relating national levels of crop damage to the abundance of large grazing birds: Implications for management. *Journal of Applied Ecology* 56: 2286-2297.

Annex 5. Indicator factsheets

I.1. Population size compared to the Favourable Reference Population (FRP)

Rationale

This indicator measures the progress towards the Fundamental Objective I. Maintain the population at a satisfactory level. The FRPs at national and flyway level are set in Chapter 2 of this AFMP. These FRPs corresponds to the ecological requirements part of Article 2 of the Birds Directive.

Indicator definition

The FRP will be monitored both on the breeding grounds of MUs 2 and 3 and at the wintering grounds for the population as a whole.

Methodology

Data collection

The assessment of the FRP will be based on monitoring protocls described in Chapter 5 of this AFMP.

Data flow

The dataflow is described in Chapter 5 of this AFMP.

Methodology for indicator calculation

Methodology is described in Chapter 5 of this AFMP.

Methodology for gap filling

Methodology for gap filling is to be agreed in 2020.

Methodology uncertainty

The pre-migration aerial surveys represent a snapshot and some flocks migt be easily missed.

I.2 Range extent compared to the Favourable Reference Range (FRR)

Rationale

This indicator measures the progress towards the Fundamental Objective I. Maintain the population at a satisfactory level. The population is considered to be maintained at a satisfactory level if the range is maintained at or above the level of the Favourable Reference Range, which is set (for most Range States) in Table 2 of this AFMP at the level of the 2003-2018 period.

Indicator definition

This indicator consists of two sub-indicators:

- Actual breeding range in proportion of the breeding FRR;
- Actual non-breeding (staging and wintering range) in proportion of the non-breeding FRR.

The breeding range includes the areas where nesting and brood rearing before fledging takes place.

According to the CMS definition, the non-breeding range includes any areas the migratory species stays in temporarily, crosses or overflies during its normal migration. Hence, the range is not restricted to key sites only, but includes all areas where the species regularly (although not necessarily) occurs annually.

Methodology

Data collection

The breeding ranges of MUs 2 and 3 are within the territories of the EU Member States. Consequently, the breeding distribution can be monitored based on the six-yearly Birds Directive Article 12 reports. The entire breeding range of MU 1 is outside of the European Union. Consequently, there are no reporting obligations under Article 12 of the EU Birds Directive. The AEWA reporting on national population status reporting does not require Range States to report on distribution or range. Therefore, special reporting should be set up to monitor the changes in range extent.

Both the breeding and non-breeding ranges of the population should be monitored following the standards set for the reporting under Article 12 of the EU Birds Directive and use the range method described in DG Environment (2017, pp. 124-128).

Considering the high costs associated with monitoring of the breeding range in Russia, it is proposed to update the range information only once during the lifespan of the ISSMP in 2027.

Data for the non-breeding range will be collected at the same time as for breeding distribution data is collected national population status reporting to AEWA (i.e. 2024). Range States are recommended to use the Range Tool[22] developed for the reporting under Article 17 of the Habitats Directive to determine the range. The recommended gap distance for the Barnacle Goose is 140 km based on Box 3.2 in Bijlsma (2019, p. 40) using a body mass value of 1.765 kg. Information on non-breeding distribution can be obtained from the national IWC scheme, goose counts, and online observation reporting portals (such as Observation.org, Ornitho, etc.) active in the respective Range States.

Data flow

Range States should calculate the range based on their distribution mapping and report it to the EGMP Data Centre by 31 December 2025.

Methodology for indicator calculation

For both sub-indicators the actual range will be compared to the national, MU and flyway level FRRs.

Methodology for gap filling

No need for gap filling is foreseen in the Range States.

Methodology uncertainty

The methodology is sensitive to changes on the edges of the range. Currently, the range method was not applied by all Range States.

References

Bijlsma, R., Agrillo, E., Attorre, F., Boitani, L., Brunner, A., Evans, P., . . . van Kleunen, A. (2019). *Defining and applying the concept of Favourable Reference Values for species and habitats under the EU Birds and Habitats Directives*. Retrieved from https://edepot.wur.nl/469035

DG Environment. (2017). *Reporting under Article 17 of the Habitats Directive: Explanatory notes and guidelines for the period 2013-2018.* In (pp. 188). Brussels: European Commission.

[22] http://cdr.eionet.europa.eu/help/habitats_art17/Reporting2019/Guidelines_for_EEA_range_tool_README_.pdf

II.1. Relative change in damage payments

Rationale

This indicator measures the progress towards the Fundamental Objective II. Minimize agricultural damage and conflicts. The most direct indicator would be the loss of yield of a given crop type caused by Barnacle Geese, aggregated from local to national and international levels. However, such measurements would be extremely costly and models for upscaling do not exist. Therefore, it is necessary to resort to measurable proxy indicators, such as (1) compensation payments or (2) subsidies, or management actions taken to prevent agricultural damage, such as (3) offtake under derogation.

Indicator definition

This indicator includes three sub-indicators (for definition and current use in the EGMP Range States, see Tombre et al. (2019)[23]:

1. Monetary compensation payments for crop damages cause by Barnacle Geese, under which farmers eligible for compensation receive public money to counterbalance for the lost crop.
2. Subsidy payments, i.e. farmers receiving public funds in order to allow goose grazing on their properties. Subsidies are usually paid in advance and may hence not directly reflect the level of damage.
3. Offtake under derogation, referring to the culling of flight-less geese (adults and young), removing of nests or eggs during summer, or geese shot outside the hunting season to protect crops.

Because the three sub-indicators are used slightly differently among Range States and do not all use a monetary currency, they will be used on a relative scale to evaluate trends in damage.

Methodology

Data collection

Data collected for the three sub-indicators at national level, species-specific and annually. Compensation payments, subsidies paid, and numbers of Barnacle Geese killed under derogation will be compiled from the national statutory authorities, who are also responsible for the quality check of the information provided. The authorities will also be asked to report any change in policies, regulations or management practices, which may influence payments or use of derogation.

Data flow

Data for each year from the period of 2020 – 2024 is to be reported to the EGMP Data Centre by 31 December 2025. Data collection shall continue also in 2025 – 2026.

Methodology for indicator calculation

The national payments and derogation information will be entered into a common database. Damage in 2020 will be set at an index of 100 for each country, and subsequent data will be indexed relatively to the starting year, taking into account the national inflation rate. An overview for all range states and the three relative sub-indicators will be updated annually.

Methodology for gap filling

No gap filling.

[23] https://egmp.aewa.info/sites/default/files/download/population_status_reports/EGMP_010_Management_measures_for_geese.pdf

Methodology uncertainty

The sub-indicators are sensitive to changes in management policies, regulations and practises. A metabase will document all the reported changes. Some countries do not have species-specific reporting of damage and can only give a rough estimate of the damage caused by Barnacle Geese. A system will have to be set up to assess the uncertainties in the reporting.

III.1 Risk of zoonotic influenza transmission to the general public

Rationale

This indicator measures the progress towards the public health component of Fundamental Objective III. Minimise the risk to public health and air safety.

Migratory geese can act as a vectors of various diseases harmful to humans and poultry (Buij *et al.*, 2017) although the general risk was considered being low in the ISSMP. Risk of zoonotic influenza transmissions has been selected as an indicator because (i) its high relevance for human health, (ii) there is an ongoing surveillance programme in the EU/EEA with quarterly reports[24]. Hence, monitoring zoonotic influenza does not require additional resources from the EGM Range States. (iii) This indicator represents not only the prevalence of the virus, but also the preparedness to avoid transmissions.

Indicator definition

Number of human cases of zoonotic influenza per year in the flyway that can be attributed to Barnacle Goose.

Methodology

Data collection

No direct reporting is required by the Range States.

Data flow

Data will be obtained by the EGMP Data Centre from the Avian Influenza overview reports published quarterly by the European Food Safety Authority (EFSA), the European Centre for Disease Prevention and Control (ECDC) and the European Union Reference Laboratory for Avian influenza (EURL).

Methodology for indicator calculation

Number of cases per year.

Methodology for gap filling

No need for gap filling is foreseen in the Range States.

Methodology uncertainty

Attribution of the source of infection might be problematic in some cases.

[24]https://www.ecdc.europa.eu/en/avian-influenza-humans/surveillance-and-disease-data/avian-influenza-overview

References

Buij, R., Melman, T. C., Loonen, M. J., & Fox, A. D. (2017). Balancing ecosystem function, services and disservices resulting from expanding goose populations. *Ambio, 46*(2), 301-318.

III.2. Number of bird strikes with aircrafts caused by Barnacle Goose

Rationale

This indicator measures the progress towards the Fundamental Objective III. Minimize the risk to public health and air safety. The frequency of bird strikes with Barnacle Goose is the direct indicator for the development in incidents, cumulated from local airports to national and international levels. The risk is likely to increase with the number of Barnacle Geese passing over airports (see Indicator III.3).

Indicator definition

The indicator is the number of bird strikes caused by Barnacle Geese in commercial airports in the Range States.

Methodology

Data collection

Data collected at airport and national level, species-specific and annually. This indicator is reported as a standard in all commercial civil airports and the airport authorities attempt to make an identification of the species causing the bird strike. Airports will be asked to report:

a) Date, time of bird strike,
b) Species, flock size, number struck,
c) Aircraft model,
d) Phase of flight (takeoff, landing, descent, climb, en route).

Bird strike data will be compiled from the national statutory authorities. The authorities will also be asked to report any change in reporting practices, which may influence the indicator.

Data flow

Data for each year from the period of 2020 – 2024 is to be reported to the EGMP Data Centre by 31 December 2025. Data collection shall continue also in 2025 – 2026.

Methodology for indicator calculation

Range States will be asked to select at least three high-risk civil commercial airports within the national range of the Barnacle Goose for reporting. The frequency of bird strikes will be listed per airport and per country. An overview for all range states will be updated annually.

Methodology for gap filling

No gap filling is necessary.

Methodology uncertainty

The frequency of bird strikes with Barnacle Goose is low in most airports. Therefore, the indicator has to be combined with III.3 to give a more reliable indication of the risk.

III.3. Number of Barnacle Geese passing over commercial airports

Rationale

This indicator measures the progress towards the Fundamental Objective III. Minimize the risk to public health and air safety. The number of Barnacle Geese passing over an airport indicates the risk of bird strikes in a given airport (Indicator III.2) and can be related to the national and international levels.

Indicator definition

The indicator is the cumulative number of Barnacle Geese passing over civil commercial airports per year in the range of the Barnacle Goose, using the same airports as in III.2.

Methodology

Data collection

Data collected at airport and national level, species-specific and annually. This indicator is reported as a standard in commercial civil airports and the airport authorities attempt to make an identification of the species passing (or landing in the airport). Airports will be asked to report:

a) Date, time of passage,
b) Species, flock size.

Barnacle Goose passage data will be compiled from the national statutory authorities. The authorities will also be asked to report any change in reporting practices, which may influence the indicator.

Data flow

Data for each year from the period of 2020 – 2024 is to be reported to the EGMP Data Centre by 31 December 2025. Data collection shall continue also in 2025 – 2026.

Methodology for indicator calculation

Range States will be asked to select at least three high-risk civil commercial airports within the national range of the Barnacle Goose for reporting. The cumulative number of Barnacle Geese passing per year will be calculated per airport. A national trend index will be calculated. The starting year will be set at an index of 100, and subsequent data will be indexed relatively to the starting year. An overview for all range states (average national indexes and relative change) will be updated annually.

Methodology for gap filling

No gap filling.

Methodology uncertainty

The ability of species identification by bird control employees has to be checked. If some airports use radar for identification, standards for species identifications have to be defined.

IV.1 Area of natural habitat or habitat of threatened species negatively affected by Barnacle Goose

Rationale

This indicator measures the progress towards Fundamental Objective IV. Minimize the risk to other flora and fauna. The risk to other flora and fauna can be induced mainly via (1) grazing of plants, e.g. the Arctic tundra vegetation, with possible knock-on consequences for the whole ecosystem or (2) eutrophication of oligotrophic lake ecosystems by goose droppings transferred from foraging grounds to roosts. However, grazing and nutrient transport is amongst the ecological functions of geese and not necessarily a damage.

Therefore, it should be assessed on a case-by-case basis and considered being a damage if it conflicts with the conservation objectives of a site.

Indicator definition

Area of natural habitat or habitat of threatened species negatively affected by Barnacle Goose. This indicator considers the natural habitats of conservation interest, which includes natural habitats listed on Annex I of the EU Habitats Directive or any other natural habitats that are of conservation interest at national level. It also includes the habitat for threatened species regardless whether the habitat is of natural origin or not. In case of such habitats, the important factor is the presence and dependence of a threatened species on the habitat, and the structure and other characteristics of the habitat. In this context, threatened species include species that are listed on Annex I of the Birds Directive or on Annexes II or IV of the Habitat Directive or listed as threatened on a European or national Red List.

Methodology

Data collection

Range States will need to collect information from the organisations responsible for managing conservation areas on the damage caused by Barnacle Goose two times during the lifespan of this AFMP. As the damage can affect a wide range of species the extent of the habitat damaged will be used as the measurement of the damage. Site management organisations should be asked to report:

a) the threatened species or habitats affected negatively by Barnacle Goose during the reporting period,
b) the location, the nature of the damage and the extent of area affected.

Data flow

Data for each year from the period of 2020 – 2024 is to be reported to the EGMP Data Centre by 31 December 2025. Data collection shall continue also in 2025 – 2026.

Methodology for indicator calculation

The EGMP Data Centre will report the total area affected and also areas by habitat types or species.

Methodology for gap filling

No need for gap filling is foreseen.

Methodology uncertainty

This indicator is dependent on the judgement of the site management organisations.

V.1 Number of people enjoying watching geese

Rationale

This indicator measures the progress towards the cultural/recreational component of Fundamental Objective V. Maximise ecosystem services.

Watching geese represents an important cultural/recreational service for many people (Buij *et al.*, 2017) and the MCDA process (Johnson, 2020) has identified that several stakeholder groups valued this highly. Unfortunately, it is highly difficult to monitor the change in the recreational value of geese. Repeated socio-economic surveys would be rather expensive. Therefore, it is suggested to use the number of people submitting Barnacle Goose observations to online observation recording portals. These portals target the general public and a very high proportion of people interested in watching birds keep records of their observations on these platforms. The main observation portals in the region all contribute to the

EuroBirdPortal. This would allow obtaining data at a very low cost. Even if the indicator would probably underestimate the number of people enjoy watching geese, it is assumed it would correlate closely with the total number of people. It is proposed to focus on the number of people rather than the number of man-days because the latter would require a different level of engagement than simple enjoyment.

Indicator definition

Change in the annual number of people submitting Barnacle Goose observations to an online portal that contributes data to the EuroBirdPortal.

Methodology

Data collection

No direct reporting is required by the Range States.

Data flow

Data will be obtained by the EGMP Data Centre from EuroBirdPortal

Methodology for indicator calculation

An annual index of the number of people submitting goose observations to the online portals will be calculated for each country and aggregated at MU and flyway level.

Methodology for gap filling

No need for gap filling is foreseen in the Range States.

Methodology uncertainty

The index might also change if the number of users is changing and it should be tested whether this has any influence on the index.

References

Buij, R., Melman, T. C., Loonen, M. J., & Fox, A. D. (2017). Balancing ecosystem function, services and disservices resulting from expanding goose populations. *Ambio*, *46*(2), 301-318.

VI.1 Relative change in cost of goose management

Rationale

This indicator measures the progress towards the Fundamental Objective VI. Minimize costs of goose management. An indicator for the successful fulfilment of this objective is that the measurable administrative costs for dealing with the many facets of goose related management and conflict are reduced with the progressive implementation of the ISSMP for the Barnacle Goose.

Indicator definition

This indicator is defined by the number of administrative man-years spent on the management of Barnacle Gooose in the Range States, including program management, communication with users, number of field assessments made, reporting (from local to international levels).

Methodology

Data collection

The EGMP Data Centre will send out a questionnaire to each Range State asking for administrative costs spent on goose management activities at various governance levels (local, regional, national).

Data flow

Data for each year from the period of 2020 – 2024 is to be reported to the EGMP Data Centre by 31 December 2025. Data collection shall continue also in 2025 – 2026.

Methodology for indicator calculation

The number of man-hours divided into different levels of governance and tasks will be amalgamated for each country and be presented in an international overview at 6- year intervals.

Methodology for gap filling

No gap filling.

Methodology uncertainty

It is important to standardize the questionnaires, but due to differences in national organisation of goose management, they will have to be tailored specifically. For some countries it may be difficult to make a quantitative assessment, and it may be necessary to resort to a qualitative assessment (increase, stable, decrease).

Annex 6. Protocols for the iterative phase

Monitoring, assessment and decision-making protocols will be developed by the EGMP Data Centre after the adoption of the AFMP.