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Interim Report of the Working Group on Fisheries-induced Evolution (WGEVO)

18–20 October 2016

Laxenburg, Austria

ICES
International Council for the Exploration of the Sea

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Contents

Executive summary

The Working Group on Fisheries-induced Evolution (WGEVO) met twice in 2016: on 27–29 September 2016 (via video-conferencing) and on 18–20 October 2016 at IIASA, Laxenburg, Austria.

WGEVO pursued its effort to assemble evidence of fisheries-induced evolution and its consequences for the conservation of biodiversity and sustainable exploitation of marine species. Specifically, 2 individual-based eco-genetic models were developed for reconstructing the historical effect of fishing on the evolution of life-history traits describing growth, maturation and reproduction during the 20th century in 2 major exploited stocks, namely northeast Arctic cod (Eikeset *et al.* 2016) and North Sea plaice (Mollet *et al.* 2016a)

WGEVO applied Evolutionary Impact Assessment, a general framework developed during the previous 3-year term of the group for assessing the management implications of fisheries-induced evolution on stocks' utilities in terms of ecosystem services, on North Sea plaice (Mollet *et al.* 2016b).

Finally, WGEVO continued the estimation of fisheries-induced Darwinian selection pressures exerted on exploited stocks' life-history traits (somatic growth, maturation traits and reproductive effort). During the previous 3-year term, the group developed a general framework for assessing these fisheries-induced selection pressures and applied it to 31 stocks. 13 new stocks were analysed this year, bringing the grand total to 44, and the calibration of the estimation algorithm is in progress for 13 additional stocks. Although results can still be considered preliminary, the main findings of this large scale analysis of fisheries-induced selection pressures on life-history traits are that:

i) Typically, fishing induces selection pressures towards earlier maturation at smaller size, reduced growth, and increased reproductive effort.

ii) Across stocks, fisheries-induced selection pressures align along two nearly independent axes: a growth axis describing negatively co-varying pressures on somatic and gonadic growth, and a maturation axis describing pressures on three maturation traits.

iii) Fisheries-induced selection pressures rise super-linearly with fishing intensities.

iv) Fisheries-induced selection pressures show high sensitivity to a fishery's size selectivity. For all considered traits and across all examined life histories, selection pressures tend to be highest when the length at which fish become exposed to significant fishing is 1-2 times larger than their maturation length. Conversely, selection pressures tend to be more benign in fisheries with a peaked (permissive slot), rather than a sigmoidal size-selectivity pattern.

A manuscript is being drafted to disseminate the results of this analysis as a peer-reviewed publication.

1 Administrative details

Working Group name

Working Group on Fisheries-induced Evolution (WGEVO)

Year of Appointment

2016

Reporting year within current cycle (1, 2 or 3)

1

Chair(s)

Bruno Ernande, France

Meeting venue

Laxenburg, Austria

Meeting dates

18–20 October 2016

2 Terms of Reference a) – z)

ToR	Description	Background	Science Plan priorities addressed	Duration	Expected deliverables
a	Provide a forum for international collaboration and exchange of emerging scientific insights on fisheries-induced adaptive changes. The activities of WGEVO will provide ICES with a basis for advice on whether and how the effects of fisheries-induced adaptive change need to be taken into account in ecosystem approach to management.	The ecosystem approach to management is the overarching motive for ICES science and management.	6, 9, 10, 11, 12, 14, 15, 27	Years 1, 2, 3	Organisation of a dedicated Theme session at ICES ASC in Year 3 Provision of summary recommendations about which stocks assessed by ICES are at most risk in terms of fisheries-induced evolution in Year 3
b	Assemble and review empirical evidence of fisheries-induced adaptive change and its consequences for the conservation of biodi-	a) Research beyond current Science Plan requirements b) Research for MSFD and GES requirements	10, 27	Years 2, 3	1 ICES publication for general audience and 1 Wikipedia article in Year 3

	versity and sustainable exploitation of marine species within an ecosystem context.	c) No requirements from other WGs			
c	Apply the Evolutionary Impact Assessment (EvoIA) framework to specific case studies in order to (i) evaluate the impact of existing management measures on fisheries-induced adaptive change; (ii) relate consequences of fisheries-induced adaptive change to stakeholder utilities and to current management objectives; (iii) evaluate possible more specific objectives for managing fisheries-induced adaptive change.	a) Research beyond current Science Plan requirements b) Research for MSFD and GES requirements c) Links with relevant Assessment WGs required	6, 12, 14, 15	Years 1, 2, 3	1 peer-reviewed publication over the 3 years
d	Develop scientific and methodological tools to monitor and respond appropriately to risks to biodiversity and sustainable exploitation posed by fisheries-induced adaptive change, with a particular emphasis on making these tools readily available for a broader range of scientists and managers.	a) Research beyond current Science Plan requirements b) Research for MSFD and GES requirements c) Links with relevant Assessment WGs required	6, 9, 11	Years 1, 2, 3	Tools (R-scripts), accompanied by 1 peer-reviewed publication over the 3 years

3 Summary of Work plan

Year 1	R scripts and table of selection differentials estimates for a range of exploited fish stocks
Year 2	Review of selection differentials of exploited fish stocks
Year 3	ICES document providing an overview of fisheries-induced evolution for a wider scientific audience, and Wikipedia article

4 List of Outcomes and Achievements of the WG in this delivery period

- **Methodological developments**
  - o Development of a general framework for assessing fisheries-induced selection pressures:

i) Improvement of the R script for estimating a stock's parameters used to calibrate the selection gradient estimation algorithm;

ii) Improvement of the 3 R scripts for selection gradient estimation corresponding to increasing levels of complexity in the description of life-history traits variability;

iii) Correction of the user manual used for dissemination within the ICES community and the wider scientific community.

(Outcome of ToR d)

- **Assessment products**
  - o The framework for estimating fisheries-induced selection pressures has been applied to 13 new exploited fish stocks, bringing the current total of stocks analysed to 44. Estimation is currently in progress for 13 additional stocks (see Table 1).

(Outcome of ToR d)

Table 1. List of exploited stocks for which fisheries-induced selection pressures have been estimated.

	Species	M/F[1]	Stock/region	Division type	Area	Status
1	American plaice	M	NW Atlantic	NAFO	3LNO	completed
2	Blue whiting	M	NE Atlantic	ICES	I–IX,XII,XIV	completed
3	Brill	M	North Sea	ICES	IV	completed
4	Capelin	M	Barents Sea	ICES	I	completed
5	Cod	M	E Baltic Sea	ICES	IIId	completed
6	Cod	M	NE Arctic	ICES	I-II	completed
7	Cod	M	North Sea	ICES	IV	completed
8	Cod	M	NW Atlantic	NAFO	3NO	completed
9	Cod	M	NW Atlantic	NAFO	3M	completed
10	Cod	M	W Baltic Sea	ICES	IIIb-c	completed
11	Haddock	M	Barents Sea	ICES	I-II	completed
12	Haddock	M	North Sea	ICES	IV	completed
13	Haddock	M	Rockall	ICES	VIb	completed
14	Herring	M	E Baltic Sea	ICES	IIId	completed
15	Herring	M	North Sea	ICES	IV	completed
16	Herring	M	North Sea	ICES	IV	completed
17	Herring	M	Nowegian Spring Spawning	ICES	II	completed
18	Horse mackerel	M	NE Atlantic			completed
19	Mackerel	M	NE Atlantic	ICES	II–IX,XII,XIV	completed
20	Norway pout	M	North Sea	ICES	IV	completed
21	Plaice	M	North Sea	ICES	IV	completed
22	Saithe	M	North Sea	ICES	IV	completed

23	Sandeel	M	North Sea	ICES	IV	completed
24	Sandeel	M	North Sea	ICES	IV	completed
25	Sandeel	M	North Sea	ICES	IV	completed
26	Sandeel	M	North Sea	ICES	IV	completed
27	Sardine	M	Portugal		n.a.	completed
28	Seabass	M	Central and southern North Sea, Irish Sea, English Channel, Bristol Channel, Celtic Sea	ICES	IVb,c-VIId-h	completed
29	Sole	M	Bay of Biscay	ICES	VIIIa	completed
30	Sole	M	E. Channel	ICES	VIId	completed
31	Sole	M	North Sea	ICES	IV	completed
32	Sole	M	W. Channel	ICES	VIIe	completed
33	Sprat	M	Baltic Sea			completed
34	Turbot	M	North Sea	ICES	IV	completed
35	Whiting	M	North Sea	ICES	IV	completed
36	Northern pike	F	USA, Wisconsin	n.a.		completed
37	Pikeperch	F	Archipelago Sea		n.a.	completed
38	Pikeperch	F	Finland	n.a.	Lake Oulujärvi	completed
39	Walleye	F	USA, Canada	n.a	Lake Erie	completed
40	Walleye	F	USA, Wisconsin	n.a	Escabana lake	completed
41	Walleye	F	USA, Wisconsin	n.a	Several lakes	completed
42	Whitefish (C. lavaretus)	F	Germany, Switzerland, Austria	n.a	Lake Constance	completed
43	Whitefish (C. palaea)	F	Switzerland	n.a.		completed
44	Yellow Perch	F	USA, Canada	n.a.	Lake Erie, West Basin	completed
45	Cod	M	Faroe Plateau	ICES	Vb1	in progress
46	Cod	M	West of Scotland	ICES	VIa	in progress
47	Four-spot me-grim	M	Bay of Biscay South, Atlantic Iberian Waters East	ICES	VIIc, Ixa	in progress
48	Haddock	M	Faroe Plateau	ICES	Vb	in progress
49	Herring	M	Gulf of Riga	n.a.	28	in progress
50	Plaice	M	Celtic Sea	ICES	VIIf,g	in progress
51	Saithe	M	Faroe Plateau	ICES	Vb	in progress
52	Sole	M	Celtic Sea	ICES	VIIf,g	in progress
53	Whiting	M	West of Scotland	ICES	VIa	in progress
54	Arctic charr	F	Norway	n.a.	Lake Takvatn	in progress

55	Brown trout	F	Norway	n.a.	Lake Takvatn	in progress
56	Walleye	F		n.a.	Mille Lacs Lake	in progress
57	Walleye	F		n.a.	Red Lake	in progress

[1] Marine/Freshwater

- **Publications**
  - Eikeset AM, Dunlop ES, Heino M, Storvik GO, Stenseth NC, Dieckmann U. 2016. Roles of density-dependent growth and life history evolution in accounting for fisheries-induced trait changes. Proceedings of the National Academy of Sciences of the United States of America, 113: 15030–15035.

    (Outcome of ToR b)
  - Mollet FM, Dieckmann U, Rijnsdorp AD. 2016a. Reconstructing the effects of life history evolution in North Sea plaice (*Pleuronectes platessa*). Marine Ecology Progress Series 542: 195-208. 10.3354/meps11441

    (Outcome of ToR b)
  - Mollet FM, Poos JJ, Dieckmann U, Rijnsdorp AD 2016b. Evolutionary impact assessment of the North Sea plaice fishery and options for mitigation. Canadian Journal of Fisheries and Aquatic Science 73: 1126–1137. Doi: 10.1139/cjfas-2014-0568

    (Outcome of ToR c)
  - Drafting of a publication presenting the results of the estimation of fisheries-induced selection gradients on a large number of stocks.

    (Outcome of ToR d)

5 Progress report on ToRs and workplan

Progress by ToR

- ToR a: Provide a forum for international collaboration and exchange of emerging scientific insights on fisheries-induced adaptive changes. The activities of WGEVO will provide ICES with a basis for advice on whether and how the effects of fisheries-induced adaptive change need to be taken into account in ecosystem approach to management.

  The working group provides the opportunity for scientists in the field to discuss and exchange ideas by organizing several meetings per year. The WGEVO has met twice in 2017: once physically for its annual meeting and once remotely through video-conferencing for an intersessional meeting.
- ToR b: Assemble and review empirical evidence of fisheries-induced adaptive change and its consequences for the conservation of biodiversity and sustainable exploitation of marine species within an ecosystem context.

  The working group continues maintaining a database on published studies on fisheries-induced evolution, in particular in age and size at maturation.

  Members of the working group have developed individual-based eco-genetic models of female North Sea plaice and northeast Arctic cod to reconstruct the historical effect of fishing on the evolution of life-history traits describing growth, maturation and reproduction of these stocks. These models successfully reproduced changes in life-history traits observed during the 20th century and helped disentangling the 3 processes potentially concurring to these, namely demographic truncation of the population's age structure, phenotypic plasticity in maturation in response to density-dependent growth and fisheries-induced evolution. The results were published in 2 peer-reviewed articles (Mollet *et al.* 2016a, Eikeset *et al.* 2016; full references in Section 4)

- ToR c: Apply the Evolutionary Impact Assessment (EvoIA) framework to specific case studies…

  During its previous 3-year term, WGEVO had developed a general framework for investigating eco-evolutionary changes in fish stocks and their utilities in terms of ecosystem services and for assessing the management implications of fisheries-induced evolution through Evolutionary Impact Assessments (EvoIAs).

  Members of the working group have applied the EvoIA framework to North Sea plaice. The results were published in a peer-reviewed article (Mollet *et al.* 2016b; full reference in Section 4).

- ToR d: Develop scientific and methodological tools to monitor and respond appropriately to risks to biodiversity and sustainable exploitation posed by fisheries-induced adaptive change, with a particular emphasis on making these tools readily available for a broader range of scientists and managers.

  During its previous 3-year term, WGEVO had developed a general framework for assessing fisheries-induced selection pressures on exploited stocks. Specifically, R scripts for estimating (i) input parameters and (ii) fisheries-induced selection pressures were developed and accompanied by a user manual for dissemination within the ICES community and the wider scientific community.

  The framework had been applied to 31 exploited stocks during the previous term, and has been applied to 13 new stocks this year for a total of 44 stocks analysed (Table 1). Estimation of fisheries-induced selection pressures is currently in progress for 13 additional stocks (Table 1). A publication presenting these results is currently being drafted and to be submitted for peer-review by the end of the 3-year term.

Science Highlights

- The three peer-reviewed publications produced by WGEVO (Eikeset *et al.* 2016, Mollet *et al.* 2016a, b) present the following research highlights

  i) The historical reconstruction of the effect of fishing on the evolution of life-history traits describing growth, maturation and reproduction during the 20th century in 2 major exploited stocks, namely northeast Arctic cod (Eikeset *et al.* 2016) and North Sea plaice (Mollet *et al.* 2016a).

  ii) The application of Evolutionary Impact Assessment, a general framework for assessing the management implications of fisheries-induced evolution through their utilities in terms of ecosystem services, on North Sea plaice (Mollet *et al.* 2016b).

- Fisheries-induced selection pressures on maturation (described by a probabilistic maturation reaction norm; PMRN), growth (described by juvenile growth potential), and reproductive investment (described by the gonadosomatic index) were estimated for 44 exploited stocks. This comprehensive analysis enables the following findings:

  i) The general pattern found through these empirical analyses agrees with theoretical expectations: on average, fisheries-induced selection pressures favour earlier maturation at smaller size (Figure 1, PMRN midpoint), reduced somatic growth (Figure 1, Growth), and increased reproductive effort (Figure 1, Gonadosomatic index or GSI).

  ii) The variation in standardized fisheries-induced selection pressures is highest for the juvenile growth potential, also as expected (Figure 1, Growth).

  iii) Across stocks, fisheries-induced selection pressures appear align along two nearly orthogonal (i.e., statistically independent) axes (Figure 2): a 'maturation axis' along which the selection pressures on PMRN midpoints on the one hand, and PMRN slopes and widths on the other, co-vary negatively and a 'growth-reproduction axis'along which the selection pressures on juvenile growth potential and gonadosomatic index co-vary negatively.

  iv) As expected, fisheries-induced selection pressures rise with fishing intensities (Figure 3). However, the increase with fishing intensity is super-linear as can be seen by comparing the results of linear regression (red line, Figure 3) to those of third order polynomial regression or of a loess smoother (black and blue lines, respectively, Figure 3).

  v) Fisheries-induced selection pressures show high sensitivity to a fishery's size selectivity. For all considered traits and across all examined life histories, selection pressures for stocks exposed to a sigmoidal or trawl-like size-selectivity tend to be highest when the length at which fish become exposed to significant fishing pressure (i.e. the length at which 50% of maximum fishing mortality is reached) is 1 to 2 times larger than their maturation length (Figure 4). As fishing targets larger sizes, selection pressures are reduced.

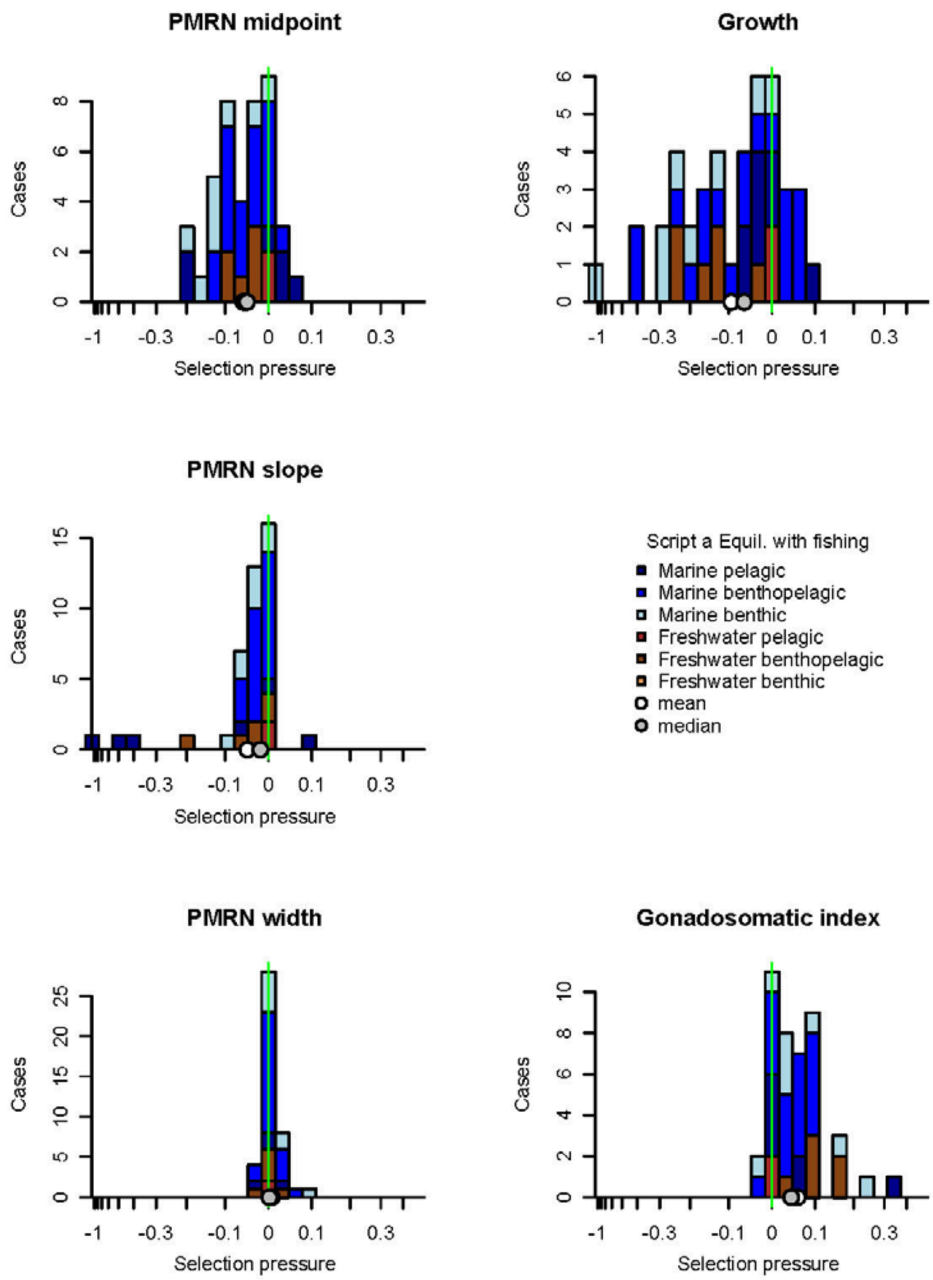

Figure 1. Frequency distributions of the standardized fisheries-induced selection pressures on the probabilistic maturation reaction norm (PMRN) midpoints, PMRN slopes, PMRN widths, juvenile growth potentials (Growth), and gonadosomatic indices of 44 exploited fish stocks. Different colours indicate different biomes, as specified by the inset legend. For each distribution, the white and grey circles on the horizontal axis indicate the distribution's mean and median, respectively, while the green vertical line indicates the absence of selection (i.e., a selection pressure of 0).

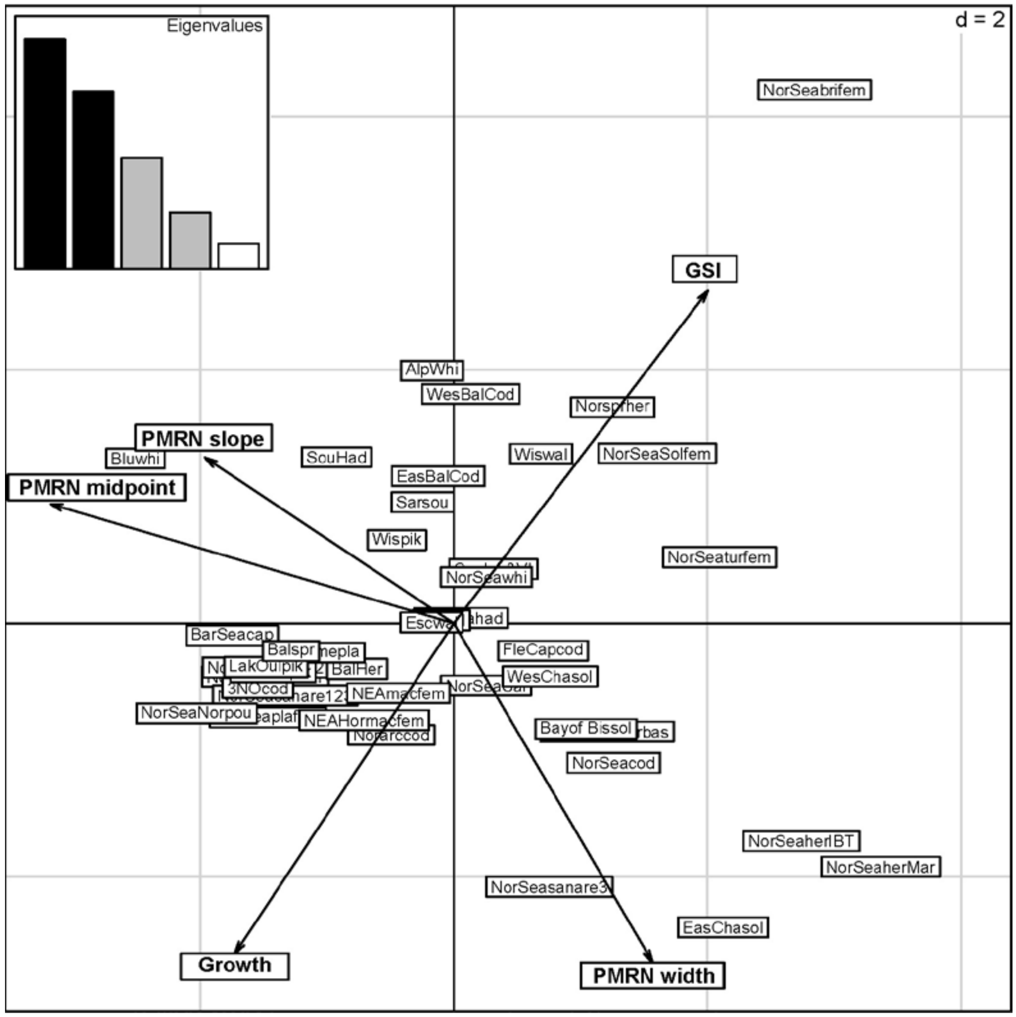

Figure 2. Principal components of the standardized fisheries-induced selection pressures on the life-history traits of 44 exploited fish stocks. Solitary labels represent the selection pressures on the five considered traits for each of the analysed stocks, while labelled arrows represent the resultant averages of these selection pressures. Stock-specific and average selection pressures are shown in relation to the first two principal components, represented by the horizontal and vertical axes, respectively. The inset shows the decreasing contributions of the first five principal components (left to right).

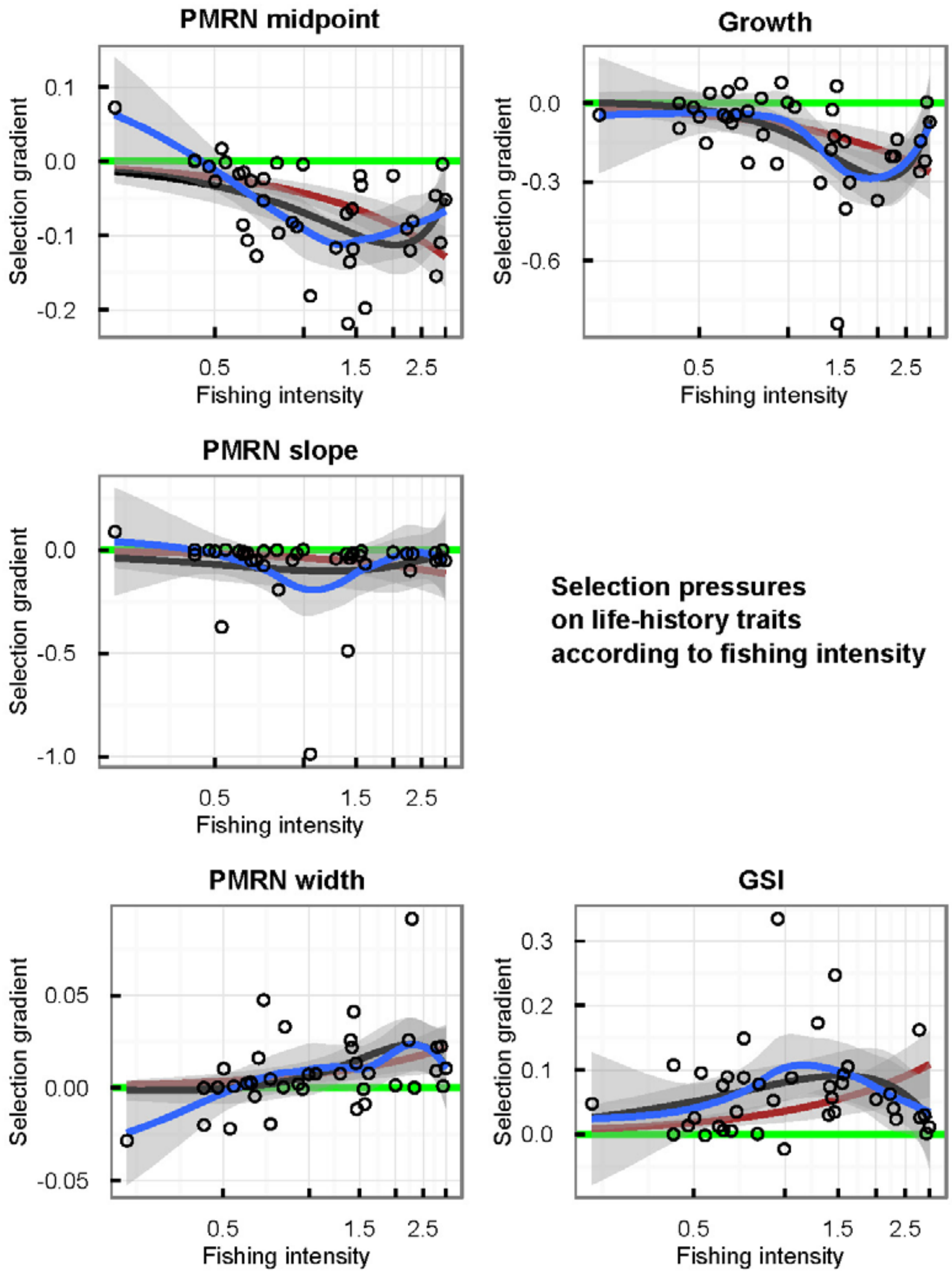

Figure 3. Standardized fisheries-induced selection pressures on the life-history traits of 44 exploited fish stocks according to fishing intensity (x-axis) computed as maximum fishing mortality rate relative to average maturation rate (obtained as the inverse of average maturation age). Note that the x-axis is on logarithmic scale. Green horizontal line indicates the absence of selection (i.e., a selection pressure of 0). The red line represents linear regression, the black line third order polynomial regression and the blue line approximation by a loess smoother.

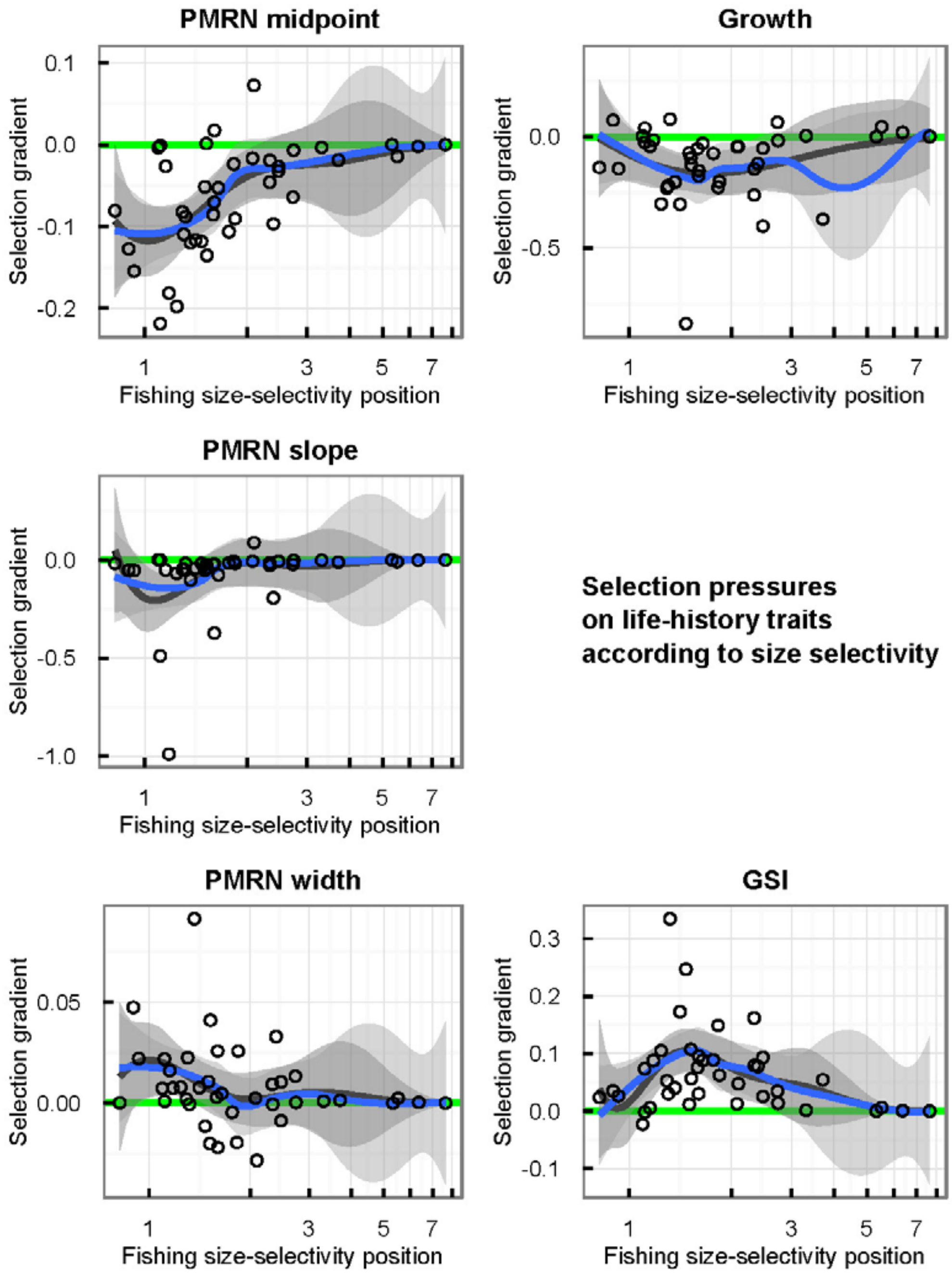

Figure 4. Standardized fisheries-induced selection pressures on the life-history traits of 40 exploited fish stocks exploited with a sigmoidal (or trawl-like) size-selectivity pattern according to fishing size-selectivity position (x-axis) computed as the length at which 50% of maximum fishing mortality is reached relative to average maturation length. Note that the x-axis is on logarithmic scale. Green horizontal line indicates the absence of selection (i.e., a selection pressure of 0). The black line third order polynomial regression with exponential decrease and the blue line approximation by a loess smoother.

6 Next meetings

The annual meeting in year 2 (2017) will be held at the International Institute for Applied Systems Analysis (IIASA, Laxenburg, Austria) on 12–14 June 2017.

Annex 1: List of participants

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