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

6–8 February 2018

Laxenburg, Austria

ICES
International Council for the Exploration of the Sea

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Executive summary

The Working Group on Fisheries-Induced Evolution (WGEVO) gathered for three annual meetings at IIASA, Laxenburg, Austria (18–20 October 2016; 12–14 June 2017; and 6–8 February 2018) and 3 virtual meetings (27–29 September 2016; 20–21 March 2017; and 5–6 April 2017) through video-conferencing. The group progressed on its 3 main objectives, namely: (i) assembling and reviewing empirical evidence of fisheries-induced evolution; (ii) applying the Evolutionary Impact Assessment (EvoIA) framework developed by the group during the previous 3-year term to specific case studies; and (iii) developing tools for scientists and managers to monitor and mitigate fisheries-induced evolution and its consequences for fisheries.

Several studies on the evidence of fisheries-induced evolution were conducted by members of the group. A field study on gonad weight recorded since the late 70s in three populations of cod off Newfoundland supported the hypothesis that fisheries-induced evolution has occurred in gonadal investment in males, but not in females (Baulier *et al.* 2017). An experimental study on a freshwater model species demonstrated that hypoxia could lead to plastic changes in life-history traits in similar to genetic changes induced by size-selective fishing, thus acting as a potential confounding factor of fisheries-induced evolution (Diaz Pauli *et al.* 2017). Two individual-based eco-genetic models were developed for reconstructing the historical effect of fishing on the evolution of 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 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 (FISP) exerted on exploited stocks' life-history traits based on the general framework developed by the group during the previous 3-year term. 28 new stocks were analysed during the current 3-year term, bringing the grand total of analysed stocks to 59, and a R notebook was produced as User manual. The main findings of this large scale analysis are that:

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

(ii) Across stocks, FSIP align along two nearly independent axes: a growth axis describing negatively covarying pressures on somatic and gonadic growth, and a maturation axis describing pressures on maturation.

(iii) FISP rise with fishing intensities for the main traits i.e. maturation propensity, growth and reproductive investment.

(iv) FISP show high sensitivity to a fishery's size selectivity. They 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, FISP tend to be more benign in fisheries with a peaked (permissive slot), rather than a sigmoidal size-selectivity pattern.

(v) Slow growing, long-lived species maturating late and large and having costly reproduction are more prone to fisheries-induced selection.

The working group suggests that continuing WGEVO for a three-year term is advisable. The benefits will be (i) the completion of the ongoing statistical analysis of the large-scale estimation of FISP and (ii) the production of a related peer-reviewed paper and Cooperative Research Report providing on overview of FISP on major exploited fish stocks.

1 Administrative details

Working Group name

Working Group on Fisheries-Induced Evolution (WGEVO)

Year of Appointment within current cycle

2016

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

3

Chair(s)

Bruno Ernande, France

Meeting venues and dates

Annual meeting: 18–20 October 2016, Laxenburg, Austria (9 participant)

Inter-session meeting: 27–29 September 2016, video-conferencing (8)

Annual meeting: 12–14 June 2017, Laxenburg, Austria (8)

Inter-session meetings: 20–21 March 2017, 5–6 April 2017, video-conferencing (8)

Annual meeting: 6–8 February 2018, Laxenburg, Austria (9)

2 Terms of Reference

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	a) Research beyond current Science Plan	10, 27	Years 2, 3	1 ICES publication for general audi-

	fisheries-induced adaptive change and its consequences for the conservation of biodiversity and sustainable exploitation of marine species within an ecosystem context.	requirements b) Research for MSFD and GES requirements c) No requirements from other WGs			ence and 1 Wikipedia article in Year 3
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 Summary of Achievements of the WG during 3-year term

- **Methodological developments**
  - 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 three R scripts for selection gradient estimation corresponding to increasing levels of complexity in the description of life-history traits variability;
    (iii) Translation of the user manual into an R Notebook for better dissemination of the methodology within the ICES community and the wider scientific community

  ➲ ***Outcome of ToR d***

- **Assessment products**
  - The framework of Evolutionary Impact Assesssment has been applied to North Sea plaice

  ➲ ***Outcome of ToR c***

  - The framework for estimating fisheries-induced selection pressures has been applied to 28 new exploited fish stocks in addition to the 31 stocks analyzed in the previous 3-year term, bringing the grand total to 59 (see Table 1).

  ➲ ***Outcome of ToR d***

Table 1. List of exploited stocks for which FISP have been estimated.

	Species	M/F[1]	Stock/region	Division type	Area	Status
1	American plaice	M	NW Atlantic	NAFO	3LNO	completed
2	Arctic charr	F	Norway	Lake Takvatn	n.a.	completed
3	Blue whiting	M	NE Atlantic	ICES	I–IX,XII,XIV	completed
4	Brill	M	North Sea	ICES	IV	completed
5	Brown trout	F	Norway	Lake Takvatn	n.a.	completed
6	Capelin	M	Barents Sea	ICES	I	completed
7	Cod	M	E Baltic Sea	ICES	IIId	completed
8	Cod	M	Faroe Plateau	ICES	Vb1	completed
9	Cod	M	Iceland	ICES	Va	completed
10	Cod	M	NE Arctic	ICES	I-II	completed
11	Cod	M	North Sea	ICES	IV	completed
12	Cod	M	NW Atlantic	NAFO	3NO	completed
13	Cod	M	NW Atlantic	NAFO	3M	completed
14	Cod	M	W Baltic Sea	ICES	IIIb-c	completed
15	Cod	M	West of Scotland	ICES	Via	completed
16	Four-spot megrim	M	Bay of Biscay South, Atlantic	ICES	VIIc, Ixa	completed

	Species	M/F[1]	Stock/region	Division type	Area	Status
			Iberian Waters East			
17	Haddock	M	Barents Sea	ICES	I-II	completed
18	Haddock	M	Faroe Plateau	ICES	Vb	completed
19	Haddock	M	Iceland	ICES	Va	completed
20	Haddock	M	North Sea	ICES	IV	completed
21	Haddock	M	Rockall	ICES	VIb	completed
22	Herring	M	E Baltic Sea	ICES	IIId	completed
23	Herring	M	Gulf of Riga	n.a.	28	completed
24	Herring	M	North Sea	ICES	IV	completed
25	Herring	M	North Sea	ICES	IV	completed
26	Herring	M	NSS/Norwegian Sea	ICES	II	completed
27	Horse mackerel	M	NE Atlantic			completed
28	Mackerel	M	NE Atlantic	ICES	II–IX,XII,XIV	completed
29	Northern pike	F	USA, Wisconsin		n.a.	completed
30	Norway pout	M	North Sea	ICES	IV	completed
31	Pikeperch	F	Archipelago Sea		n.a.	completed
32	Plaice	M	Celtic Sea	ICES	VIIf,g	completed
33	Plaice	M	North Sea	ICES	IV	completed
34	Saithe	M	Faroe Plateau	ICES	Vb	completed
35	Saithe	M	Iceland	ICES	Va	completed
36	Saithe	M	North Sea	ICES	IV	completed
37	Sandeel	M	North Sea	ICES	IV area 1	completed
38	Sandeel	M	North Sea	ICES	IV area 2	completed
39	Sandeel	M	North Sea	ICES	IV area 3	completed
40	Sardine	M	Portugal	ICES	VIIIc-Ixa	completed
41	Seabass	M	Central and southern North Sea, Irish Sea, English Channel, Bristol Channel, Celtic Sea	ICES	IVb,c-VIId-h	completed
42	Sole	M	Bay of Biscay	ICES	VIIIa	completed
43	Sole	M	Celtic Sea	ICES	VIIf,g	completed
44	Sole	M	E. Channel	ICES	VIId	completed
45	Sole	M	North Sea	ICES	IV	completed
46	Sole	M	W. Channel	ICES	VIIe	completed
47	Sprat	M	Baltic Sea	ICES	IIId	completed
48	Turbot	M	North Sea	ICES	IV	completed
49	Walleye	F	USA, Canada	Lake Erie	n.a.	completed
50	Walleye	F	Canada, Ontario	Mille Lacs Lake, USA	n.a.	completed
51	Walleye	F	USA, Minesota	Red Lake	n.a.	completed

	Species	M/F[1]	Stock/region	Division type	Area	Status
52	Walleye	F	USA, Wisconsin	Escabana lake	n.a.	completed
53	Walleye	F	USA, Wisconsin	Several lakes	n.a.	completed
54	Whitefish (Coregonus lavaretus)	F	Germany, Switzerland, Austria	Lake Constance	n.a.	completed
55	Whitefish (Coregonus lavaretus)	F	Norway	Lake Stuorajavri	n.a.	completed
56	Whitefish (Coregonus palaea)	F	Switzerland		n.a.	completed
57	Whiting	M	North Sea	ICES	IV	completed
58	Whiting	M	West of Scotland	ICES	Via	completed
59	Yellow Perch	F	USA, Canada	Lake Erie	West Basin	completed

[1] Marine/Freshwater

- **Publications**

Baulier, L., Morgan, M. J., Lilly, G. R., Dieckmann, U., and Heino, M. 2017. Reproductive investment in Atlantic cod off Newfoundland: contrasting trends between males and females. FACETS, 2: 660-681.

➲ ***Outcome of ToR b***

Díaz Pauli, B., Kolding, J., Jeyakanth, G., and Heino, M. 2017. Effects of ambient oxygen and size-selective mortality on maturation and growth in guppies. Conservation Physiology, 5: cox010.

➲ ***Outcome of ToR b***

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 Final report on ToRs, workplan and Science Implementation Plan

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 2016, thrice in 2017 and once in 2018: thrice physically for its annual meetings and thrice remotely through video-conferencing for intersessional meetings.

WGEVO was also involved in submitting a theme session proposal for the 2018 ICES Annual Science Conference ("Adapting exploited fish stocks in the face of global change: from multiple selection pressures to adaptive changes and their impacts on ecosystem services"). This theme session aimed at providing a forum for exchanging and reviewing results of cutting edge research on adaptive changes of any phenotypic trait (life-history, phenology, migration, behavior, physiology, morphology) in exploited stocks in response to any component of global change (e.g. exploitation, climate change, habitat fragmentation, increased nutrient and contaminant loads, and biological invasions). However, this theme session was not selected.

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.

Besides members of WGEVO studied temporal changes in reproductive investment of three populations of cod off Newfoundland using time series of data on standardized gonad weight since the late 70s. They showed that, after accounting for the main potential plastic (environmental parameters) and allometric (individual charateristics) effects affecting reproductive investment, there were residual trends of increased gonadal investments in males during the earlier part of the time series when mortality was high, with the trends leveling off or reversing after the later imposition of fishing moratoria. These temporal trends are compatible with theoretical expectations on fisheries-induced evolution. In contrast, the hypothesis of fisheries-induced evolution is not supported for females. These results were published in a peer-reviewed article (Baulier *et al.* 2017; see full reference in Section 4).

Some members of the working group have also developed an experimental test of the effect of both reduced ambient oxygen and size-dependent mortality on growth, maturation and reproduction using a freshwater model species, namely guppies. They showed that hypoxia leads to plastic changes in these life-history traits (stunting, early maturation and high reproductive investment) in a direction similar to that of genetic changes induced by size-selective fishing. Ambient oxygen and hypoxia related to eutrophication and global warming is thus to be taken into account in the causal interpretation of ex-

ploited fish stocks' life-history changes. These results were published in a peer-reviewed article (Diaze Pauli *et al.* 2017; see full reference in Section 4).

Finally, 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 strcuture, 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 consequences on stocks' 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 28 new stocks during the current 3-year term for a total of 59 stocks analyzed (Table 1). The statistical analysis of exogeneous (fishing intensity, fishing size-selectivity) and endogeneous (stocks life-history characteristics) determinants of fisheries-induced selective pressures is currently in progress. A R notebook was produced as User manual and a publication presenting these results is currently being drafted.

Science Highlights

- The five peer-reviewed publications produced by WGEVO (Eikeset *et al.* 2016, Mollet *et al.* 2016a, b, Baulier *et al.* 2017, Diaz Pauli *et al.* 2017) present the following research highlights:
  (i) The statistical analysis of time series of data on standardized gonad weight since the late 70s in three populations of cod off Newfoundland supports the hypothesis that fisheries-induced evolution has occurred in gonadal investment in males, but not in females, and suggest that gonadal invest-

ment is more important for male reproductive success than expected in this lekking species (Baulier *et al.* 2017).

(ii) The experimental demonstration on a freshwater model species that hypoxia or reduced ambient oxygen can lead to plastic effects on growth, maturation and reproduction in a direction similar to that of genetic changes induced by size-selective fishing, thus acting as a potential confounding factor of fisheries-induced evolution (Diaz Pauli *et al.* 2017).

(iii) 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).

(iv) 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 59 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 aligned along two nearly orthogonal (i.e., statistically independent) axes (Figure 2): a 'maturation axis' along which the selection pressures on PMRN intercept and slope co-vary positively 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 for the main traits, i.e., maturation propensity (PMRN intercept), growth and gonodasomatic index (Figure 3).

  (v) Fisheries-induced selection pressures show high sensitivity to a fishery's size selectivity. For the main traits (PMRN intercept, growth, GSI) 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.

(vi) Selection pressures rise with the fishing-induced proportion of mortality (Figure 5), which means that they increase with fishing mortality relative to total mortality but also that they diminish with increasing natural mortality relative to total mortality.

(vii) Selection pressures rise with the gonado-somatic ratio (Figure 6), i.e. with increasing reproductive investment and with decreasing somatic investment, as well as with age and length at maturation (Figure 7-8).

(viii) It results from (vi) and (vii) that slow growing, long-lived species maturating late and large and having costly reproduction are more prone to fisheries-induced selection.

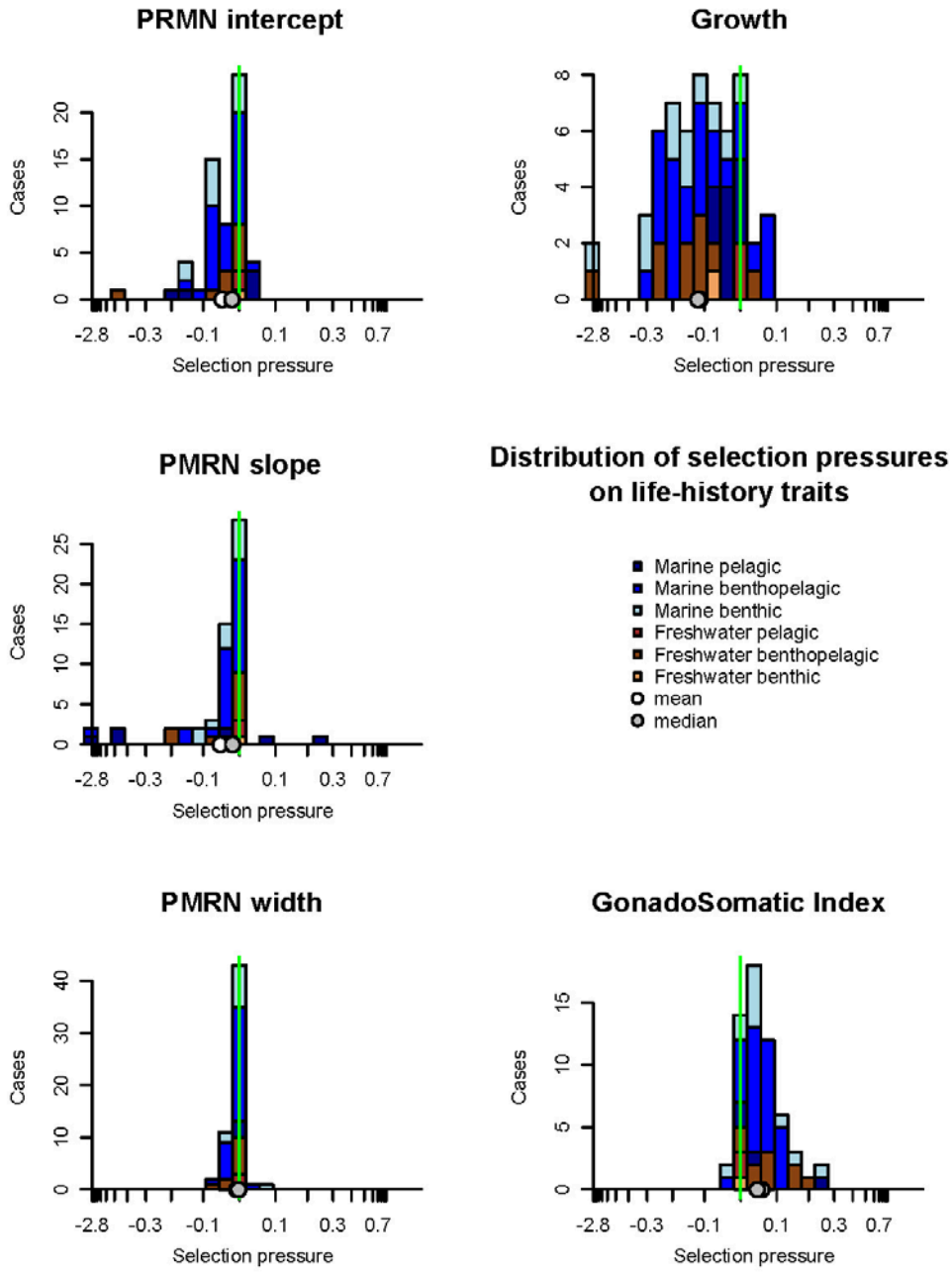

Figure 1. Frequency distributions of the standardized fisheries-induced selection pressures on the probabilistic maturation reaction norm (PMRN) intercepts, PMRN slopes, PMRN widths, juvenile growth potentials (Growth), and gonadosomatic indices (GSI) of 59 exploited fish stocks. Different colours indicate 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).

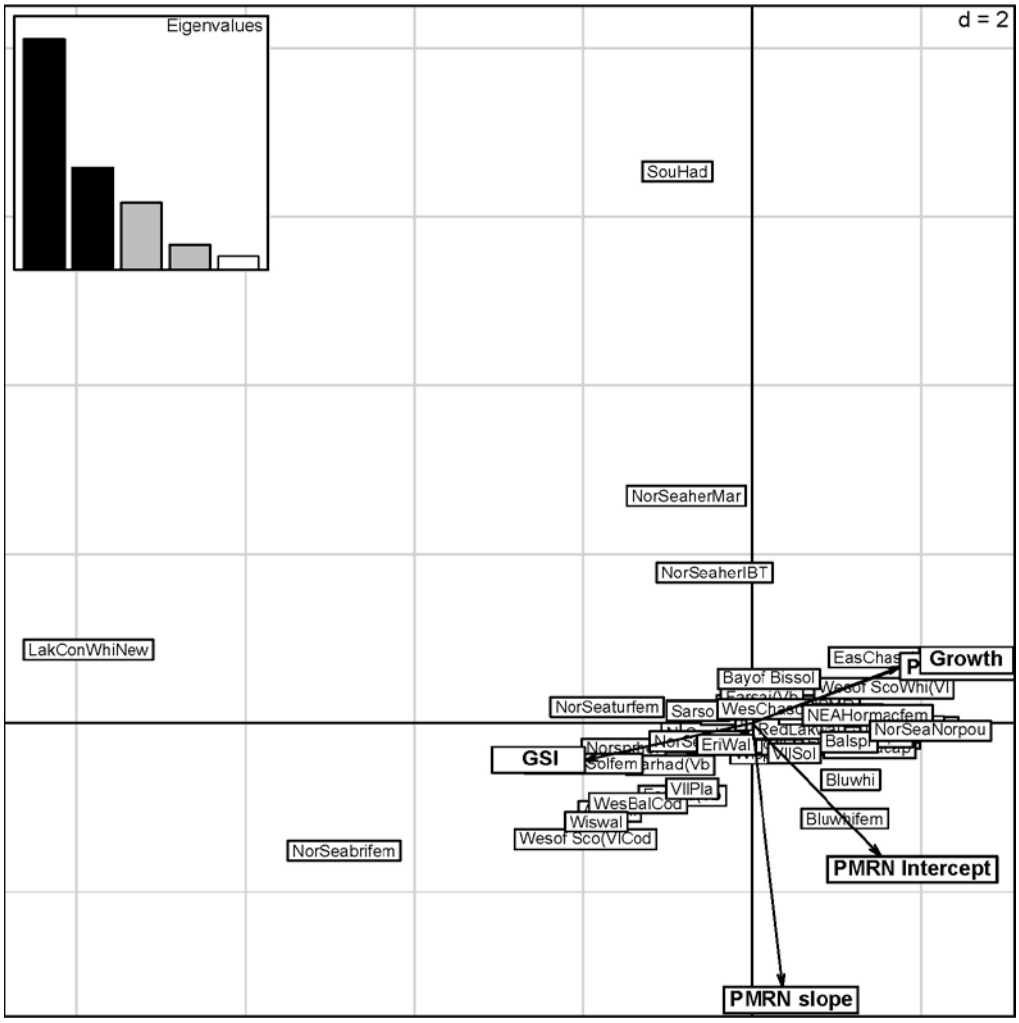

Figure 2. Principal components of the standardized fisheries-induced selection pressures on the life-history traits of 59 exploited fish stocks. Solitary labels represent the selection pressures on the five considered traits for each of the analysed stocks, while labelled arrows represent the resultant 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).

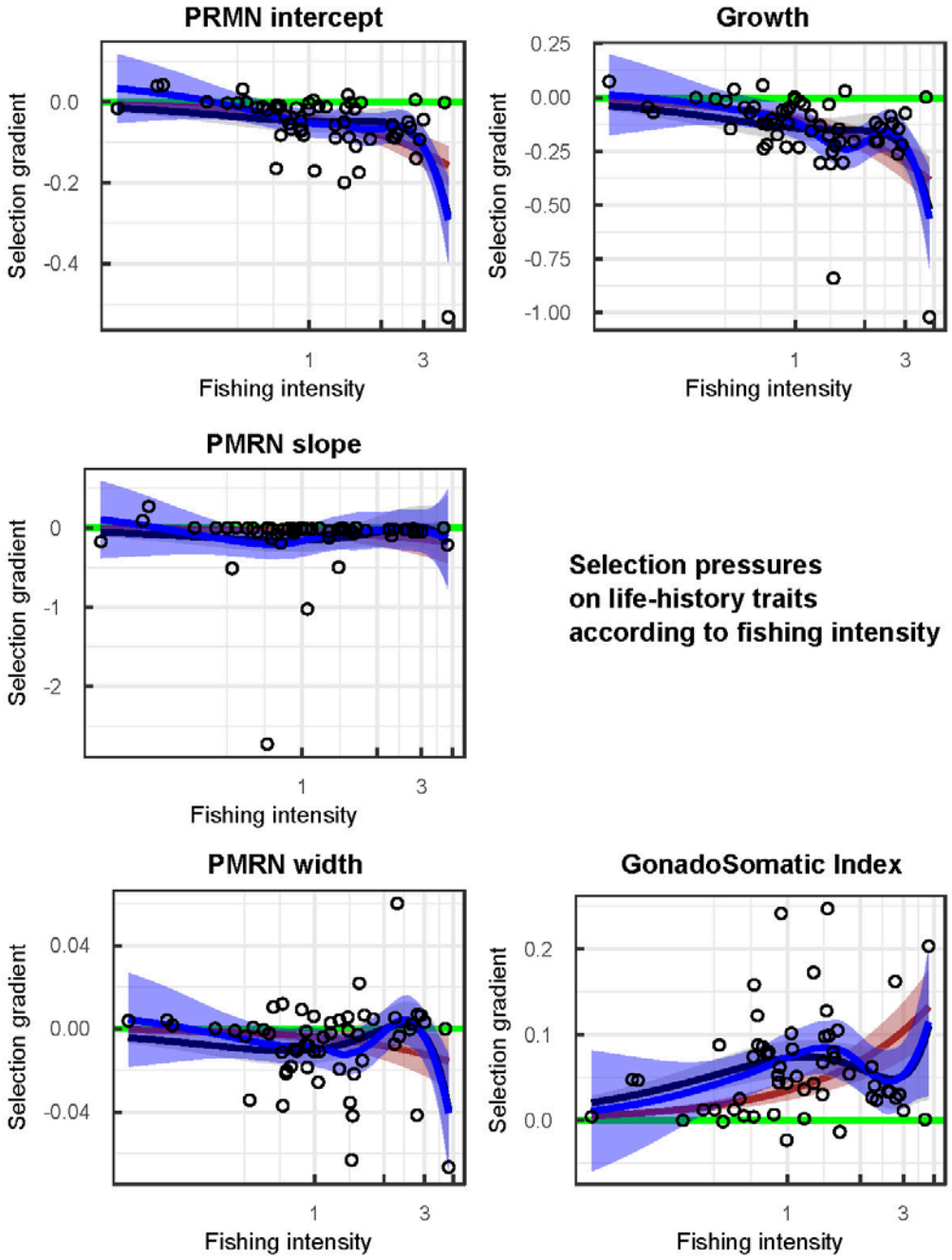

Figure 3. Standardized fisheries-induced selection pressures on the life-history traits of 59 exploited fish stocks according to fishing intensity (x-axis) computed as maximum fishing mortality rate relative to average maturation rate (obtained as the inverse of average maturation age). Note that the 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.

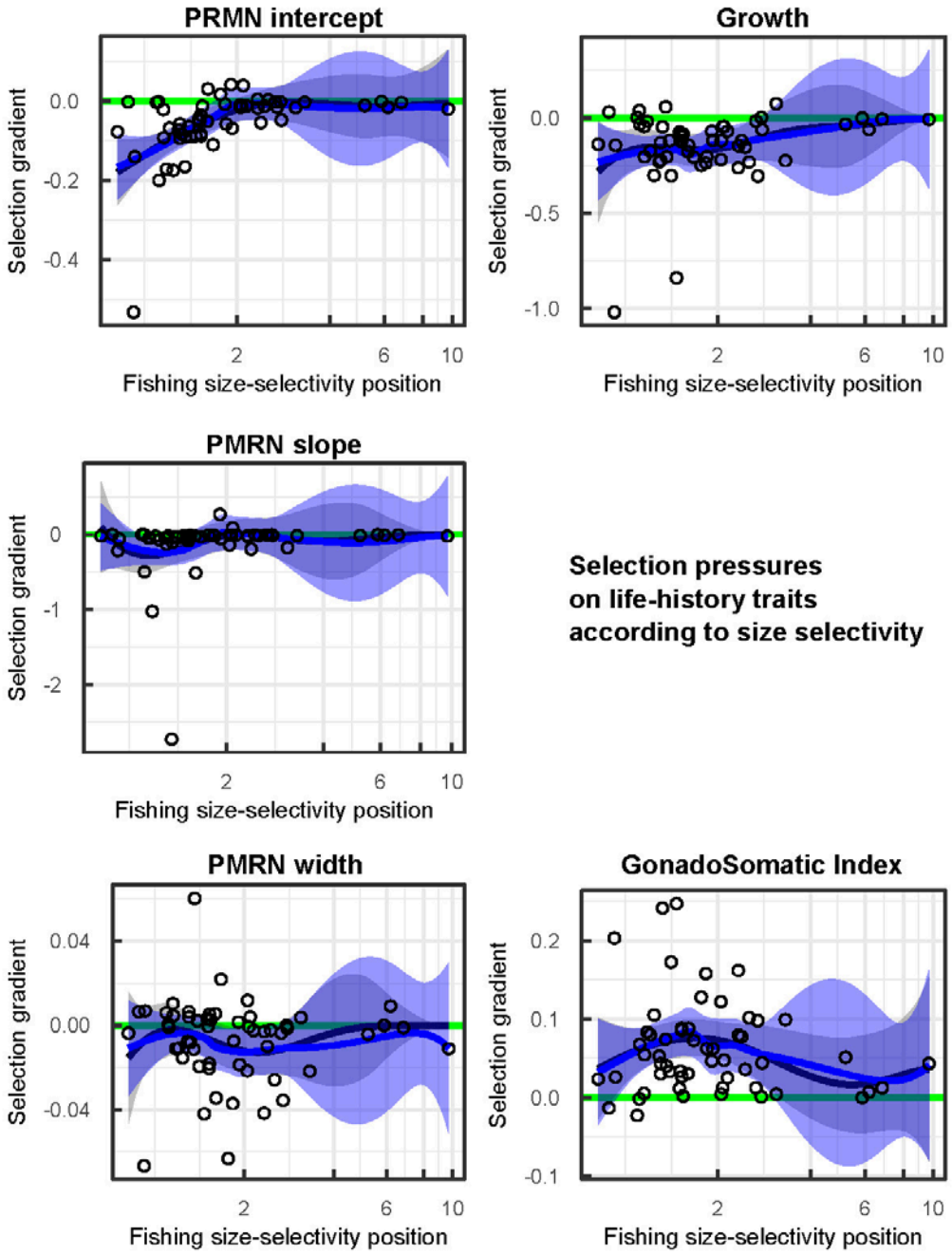

Figure 4. Standardized fisheries-induced selection pressures on the life-history traits of 53 exploited fish stocks exploited with a sigmoidal (or trawl-like) size-selectivity pattern according to fishing size-selectivity position (x-axis) computed as the length at which 50% of maximum fishing mortality 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 represents third order polynomial regression with exponential decrease and the blue line approximation by a loess smoother.

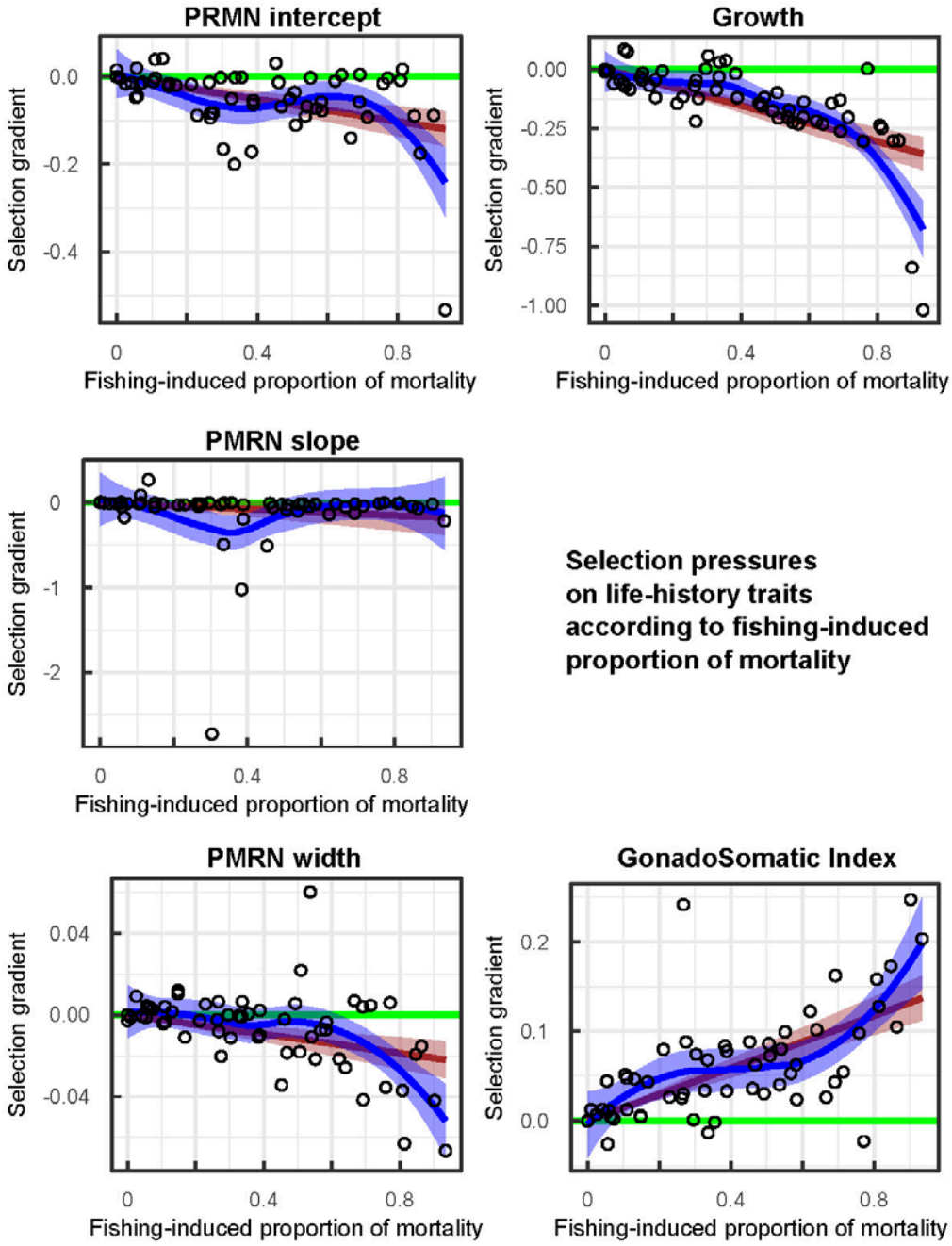

Figure 5. Standardized fisheries-induced selection pressures on the life-history traits of 59 exploited fish stocks according to fishing-induced proportion of mortality (x-axis) computed as F/Z with $Z = F + M$. Green horizontal line indicates the absence of selection (i.e., a selection pressure of 0). The red line represents linear regression and the blue line approximation by a loess smoother.

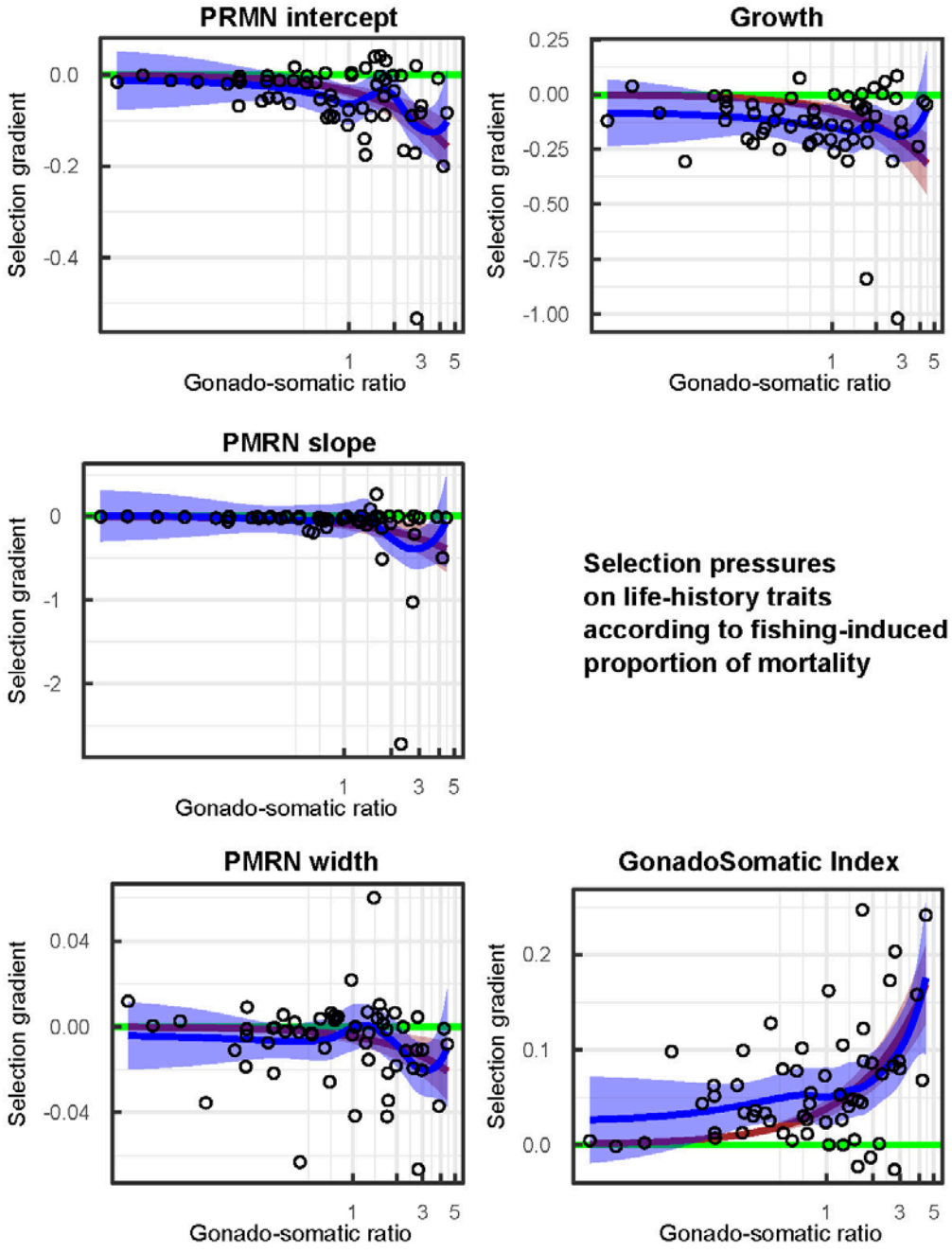

Figure 6. Standardized fisheries-induced selection pressures on the life-history traits of 59 exploited fish stocks according to gonado-somatic ratio (x-axis) i.e. the ratio of energy allocated to gonads against that allocated to soma during adulthood. Note that the x-axis is on logarithmic scale. Green horizontal line indicates the absence of selection (i.e., a selection pressure of 0). The red line represents linear regression and the blue line approximation by a loess smoother.

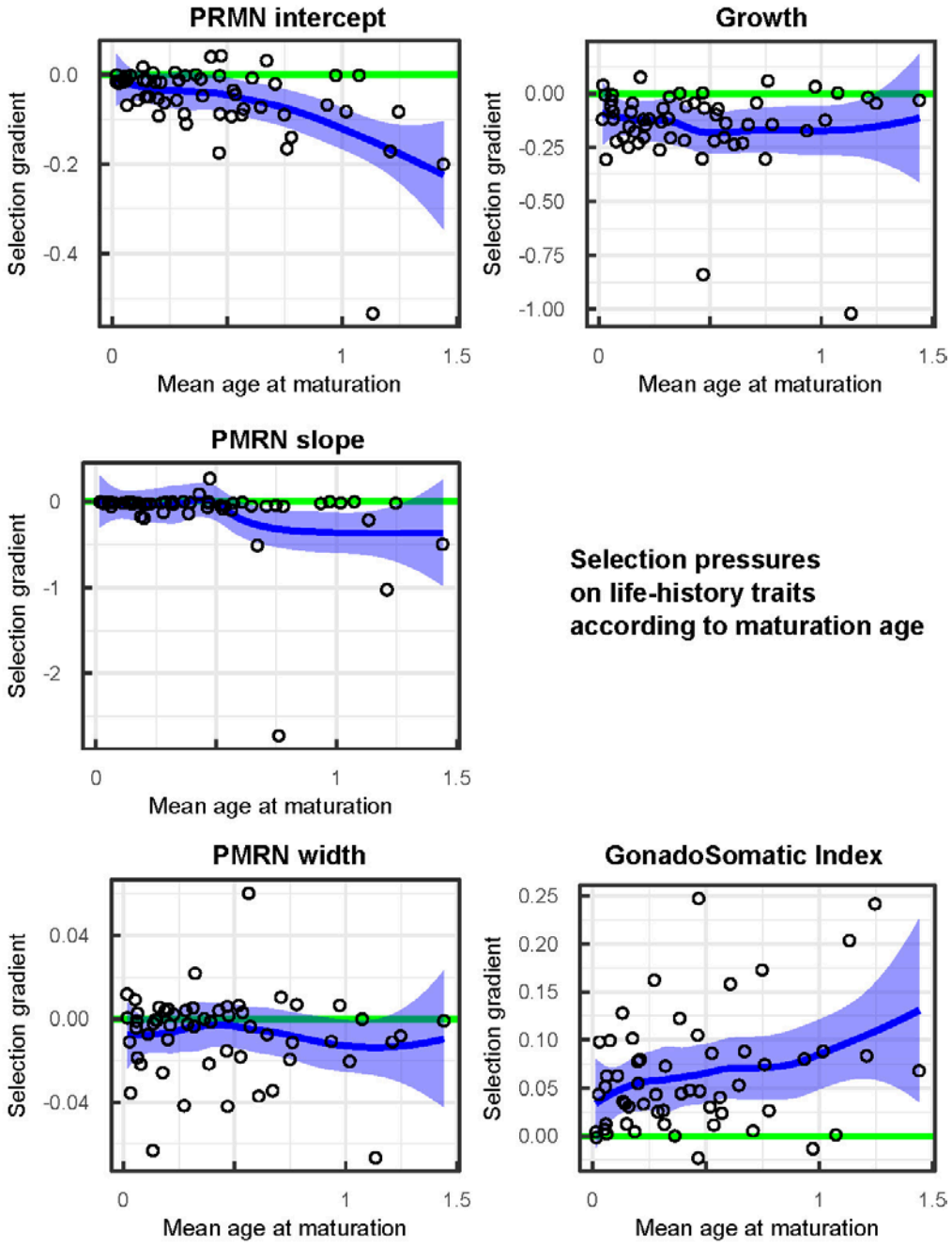

Figure 7. Standardized fisheries-induced selection pressures on the life-history traits of 59 exploited fish stocks according to mean age at maturation (x-axis) normalized by the age at which half of the maximum asymptotic length is reached. Note that the x-axis is on logarithmic scale. Green horizontal line indicates the absence of selection (i.e., a selection pressure of 0) and the blue line is an approximation by a loess smoother.

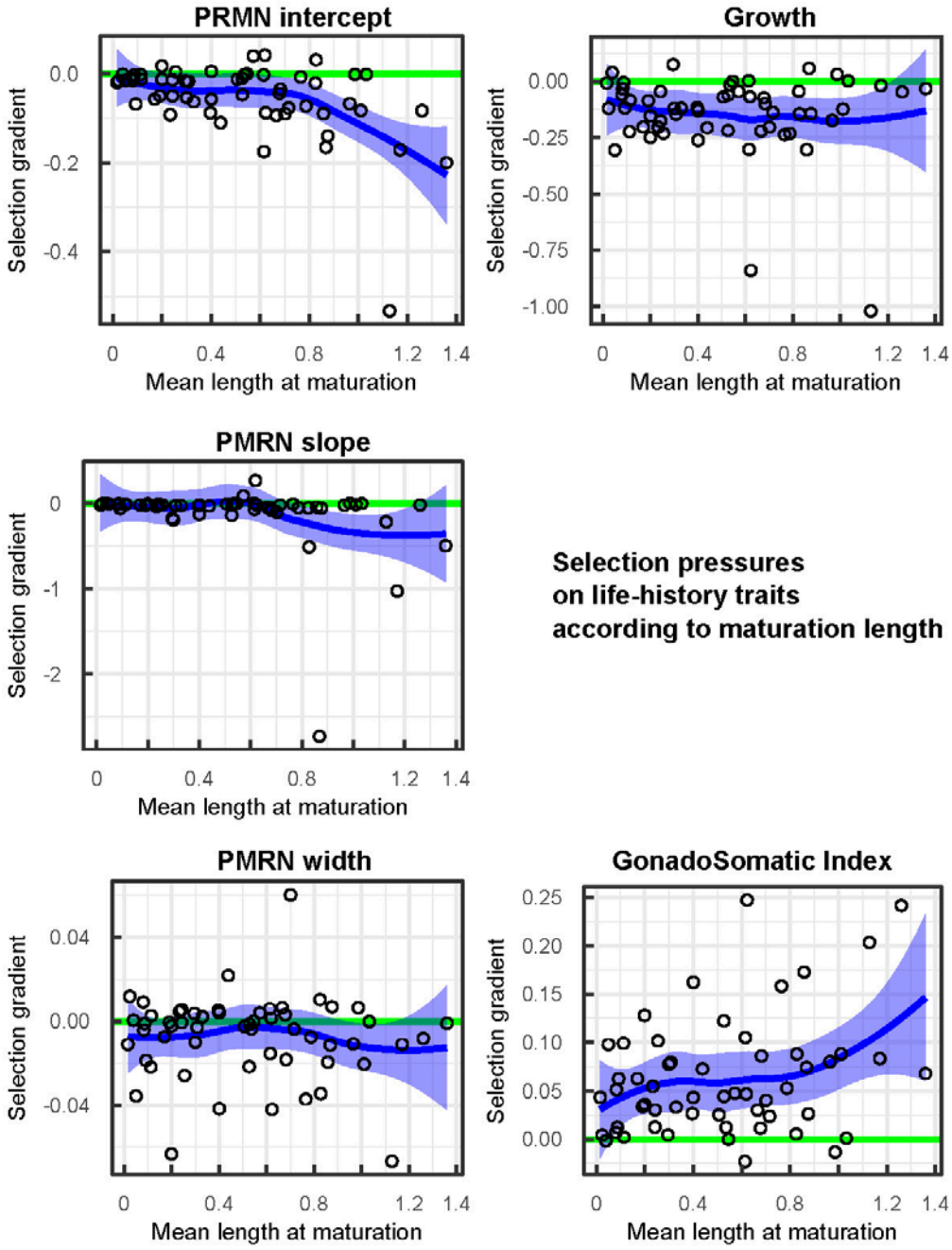

Figure 8. Standardized fisheries-induced selection pressures on the life-history traits of 59 exploited fish stocks according to mean length at maturation (x-axis) normalized by half the maximum asymptotic length. Note that the x-axis is on logarithmic scale. Green horizontal line indicates the absence of selection (i.e., a selection pressure of 0) and the blue line is an approximation by a loess smoother.

6 Summary of Working Group self-evaluation

A copy of the full Working Group self-evaluation is given in Annex 4.

Annex 1: List of participants

Name	Institute	Country (of institute)	Email
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Annex 2: WGEVO draft resolution 2019–2021

The **Working Group on Fisheries-Induced Evolution** (WGEVO), chaired by Bruno Ernande, France, will work on ToRs and generate deliverables as listed in the Table below.

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2019	TBD	TBD	Interim report by end of July 2019	
Year 2020			Interim report by end of July 2020	Change of Chair
Year 2021			Final report by end of July 2021	

ToR descriptors

ToR	Description	Background	Science Plan topics 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.	a) Science Requirements b) Advisory Requirements		Years 1, 2, 3	Organisation of a dedicated Theme session at ICES ASC in Year 1 or 2 Provision of summary recommendations about which stocks assessed by ICES are at most risk in terms of fisheries-induced evolution in Year 2
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.	a) Science Requirements		Years 2, 3	Joint projects and publications among participants and others A Cooperative Research Report in Year 2
c	Develop scientific and methodological tools to monitor and respond appropriately to risks to biodiversity and sus-	a) Science Requirements b) Advisory Requirements		Years 1, 2, 3	Methodological tools for fisheries-induced selection pressure estimation (R-scripts)

	tainable 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.			with a R notebook as a User, accompanied by 1 peer-reviewed publication on fisheries-induced selection pressures
d	Link methodological tools to estimate fisheries-induced selection to stock assessment procedure to generalize fisheries-induced selection monitoring to any analytically assessed stock	a) Science Requirements b) Advisory Requirements	Years 2, 3	Automation of fisheries-induced selection pressure estimation by using stock assessment outputs Collaboration with stock assessment WGs

Summary of the Work Plan

Year 1	Review and discuss ongoing and recently completed research in the field Statistical analysis of exogeneous (fishing characteristics) and endogeneous (stocks life-history characteristics) determinants of fisheries-induced selective pressures Complete and submit a manuscript on fisheries-induced selection pressures and their determinants in exploited fish stocks together with R scripts and User guide for fisheries-induced selection pressures estimation
Year 2	Review and discuss ongoing and recently completed research in the field Write and submit a Cooperative Research Report on the evidence for the incidence and consequence of fisheries-induced evolution across a wide range of fish stocks Start automating fisheries-induced selection pressure estimation based on stock assessment outputs
Year 3	Review and discuss ongoing and recently completed research in the field Finalize automation of fisheries-induced selection pressure estimation based on stock assessment outputs Discuss future research needs Write the final 3-year term report

Supporting information

Priority	The activities of the Working Group on Fisheries-induced Evolution 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 present and future management. Due to the potentially long lasting effects of fisheries-induced evolutionary changes, such advice is needed in relation with the precautionary approach, the ecosystem approach, biodiversity conservation, and the evaluation of risk and uncertainty.
Resource requirements	The research activities providing input to WGEVO are ongoing, and corresponding resources have been committed by the engaged institutions. The administrative resources for convening the annual WGEVO meeting are negligible.
Participants	The Group is normally attended by 8–10 members and guests.

Secretariat facilities	None.
Financial	No financial implications.
Linkages to ACOM and groups under ACOM	Linkage to Assessment WGs under ACOM
Linkages to other committees or groups	Linkage to SCICOM
Linkages to other organizations	None

Annex 4: WGEVO self-evaluation

1) Name: Working Group on Fisheries-Induced Evolution

2) Year of appointment: 2016

3) Chair: Bruno Ernande, France

4) Annual meeting: 18–20 October 2016, Laxenburg, Austria, (9 participants)

Inter-session meeting: 27–29 September 2016, Video-conferencing , (8 participants)

Annual meeting: 12–14 June 2017, Laxenburg, Austria, (8 participants)

Inter-session meetings: 20-21 March 2017, 5-6 April 2017, Video-conferencing, (8 participants)

Annual meeting: 6–8 February 2018, Laxenburg, Austria, (9 participants)

WG Evaluation

5) If applicable, please indicate the research priorities (and sub priorities) of the Science Plan to which the WG make a significant contribution.

6. *Investigate linear and non-linear ecological responses to change, the impacts of these changes on ecosystem structure and function and their role in causing recruitment and stock variability, depletion and recovery*.

WGEVO has developed a framework for Evolutionary Impact Assessment (EvoIA) that allows investigating linear and nonlinear eco-evolutionary changes in fish stocks and their utility in terms of ecosystem services and applied it to North Sea plaice (ToR c).

11. *Develop methods to quantify multiple direct and indirect impacts from fisheries as well as from mineral extraction, energy generation, aquaculture and other anthropogenic activities and estimate the vulnerability of ecosystems to such impacts.*

WGEVO has developed methodological tools to estimate fisheries-induced selection pressures and applied them to a range of exploited freshwater and marine fish stocks (ToR d).

WGEVO's EvoIA was applied to North Sea plaice to (i) evaluate the impact of fishing and existing management measures on fisheries-induced adaptive change; and (ii) relate consequences of fisheries-induced adaptive change to stakeholder utilities (here yield) and to current management objectives (ToR c).

12. *Develop approaches to mitigate impacts from these activities, particularly reduction of non-target mortalities and enhancement/restoration of habitat and assess the effects of these mitigations on marine populations*

WGEVO's EvoIA framework allowed evaluating management scenarios that help mitigate fisheries-induced adaptive change in North Sea plaice (ToR c).

15. *Develop tactical and strategic models to support short and long term fisheries management and governance advice and increasingly incorporate spatial components in such models to allow for finer scale management of marine habitats and populations*

WGEVO developed tactical eco-genetic models on northeast Arctic cod and North Sea plaice (ToR b).

6) In bullet form, list the main outcomes and achievements of the WG since their last evaluation. Outcomes including publications, advisory products, modelling outputs, methodological developments, etc.

Publications

- **Publications**
  - Baulier, L., Morgan, M. J., Lilly, G. R., Dieckmann, U., and Heino, M. 2017. Reproductive investment in Atlantic cod off Newfoundland: contrasting trends between males and females. FACETS, 2: 660-681.

  ➲ ***Outcome of ToR b.***

  - Díaz Pauli, B., Kolding, J., Jeyakanth, G., and Heino, M. 2017. Effects of ambient oxygen and size-selective mortality on maturation and growth in guppies. Conservation Physiology, 5: cox010.

  ➲ ***Outcome of ToR b.***

  - 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.***

- **Methodological developments**
  - Development of a general framework for assessing fisheries-induced selection pressures: R scripts and a R notebook as User manual for dissemination within the ICES community and the wider scientific community.

  ➲ ***Outcome of ToR d.***

- **Assessment products**
  - The EvoIA framework has been applied ot North Sea plaice fishery (Mollet *et al.* 2016b).

  ➲ ***Outcome of ToR c.***

- The framework for estimating fisheries-induced selection pressures has been applied to 28 new exploited fish stocks thus bringing teh grand total of analyzed stocks to 59.

➲ ***Outcome of ToR d.***

7) Has the WG contributed to Advisory needs? If so, please list when, to whom, and what was the essence of the advice.

8) Please list any specific outreach activities of the WG outside the ICES network (unless listed in question 6). For example, EC projects directly emanating from the WG discussions, representation of the WG in meetings of outside organizations, contributions to other agencies' activities.

9) Please indicate what difficulties, if any, have been encountered in achieving the workplan.

- ToR a: The foreseen theme session at ICES ASC planned as a deliverable of ToR a was submitted but not selected
- ToR d: During this 3-year term, WGEVO almost doubled the number of stocks for which fisheries-induced selection pressures were estimated (from 31 to 59) This task as well as several adjustments of the estimation procedure that appeared necessary as new stocks were analyzed have taken longer than anticipated. Hence, the statistical analysis of the determinants of fisheries-induced selection pressures was delayed together with the comprehensive review of the results that was planned in a peer-reviewed publication.
- ToR b: A Cooperative Research report had been planned for year 3 on the basis of an overview of the results of the project on fishing-induced selection pressures (ToRc). Given the delay in the latter, the CRR is postponed until definitive results are available.

Future plans

10) Does the group think that a continuation of the WG beyond its current term is required? (If yes, please list the reasons)

The group suggests that continuing WGEVO for a three-year term is advisable. Such an extension is indeed necessary to accomplish the following tasks:

- Finalize the statistical analysis of endogeneous (life-history characteristics) and exogeneous (fishing characteristics) determinants of fisheries-induced selection gradients estimated for 59 stocks (ToR d).
- Write a peer-review publication disseminating the results on fisheries-induced selection pressures (ToR d)
- Produce an Cooperative Research Report about fisheries-induced evolution that includes the conclusions of the review on fisheries-induced selection pressures (ToR b).

In addition, the suggested new three-year term will allow the further development of some ToRs as listed below:

- ToR e: Automate the estimation of fisheries-induced selection gradients directly based on stock-assessment outputs (this will benefit from a closer liaison with stock-assessment working groups; see below).

11) If you are not requesting an extension, does the group consider that a new WG is required to further develop the science previously addressed by the existing WG.

(*If you answered YES to question 10 or 11, it is expected that a new Category 2 draft resolution will be submitted through the relevant SSG Chair or Secretariat*.)

12) What additional expertise would improve the ability of the new (or in case of renewal, existing) WG to fulfil its ToR?

Expertise in FLR and/or stock assessment would help in developing ToR e by automating selection-pressure estimations directly based on stock-assessment outputs.

13) Which conclusions/or knowledge acquired of the WG do you think should be used in the Advisory process, if not already used? (please be specific)

Estimates of fisheries-induced selection gradients can and should be used in the advisory process. These estimates could be produced and updated on a regular basis during benchmarks and/or integrated ecosystem assessments. Estimation algorithms could then be used to forecast future selection gradients based on the projections by the stock-assessment working groups. This would allow stock assessments to cover the effects of TAC recommendations on fisheries-induced selection gradients.