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Interim Report of the Working Group on Fisheries-induced Evolution

12–14 June 2017

Laxenburg, Austria

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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Contents

Executive summary

The Working Group on Fisheries-induced Evolution (WGEVO) held two remote meetings in 2017 (20–21 March and 5–6 April) and one physical meeting at IIASA, Laxenburg, Austria, 12–14 June 2017.

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, it was demonstrated experimentally 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). A field study on gonad weight recorded 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 investment is more important for male reproductive success than expected in this lekking species (Baulier *et al.* 2017).

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 44 stocks until last year. 13 new stocks were analysed this year, bringing the grand total to 57. The estimation is still in progress for a few additional stocks but WGEVO will complete the estimation part of the project by the end of the year. 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 covarying pressures on somatic and gonadic growth, and a maturation axis describing pressures on maturation.

iii) Fisheries-induced selection pressures rise with fishing intensities for the main traits i.e. maturation propensity, growth and reproductive investment.

iv) Fisheries-induced selection pressures show high sensitivity to a fishery's size selectivity. For the main 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.

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

Statistical analyses to confirm these trends are in progress and 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)

2

Chair(s)

Bruno Ernande, France

Meeting venue

Laxenburg, Austria

Meeting dates

12–14 June 2017

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 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) 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**
  - 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 57 (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	completed
46	Cod	M	West of Scotland	ICES	VIa	completed
47	Four-spot me-grim	M	Bay of Biscay South, Atlantic Iberian Waters East	ICES	VIIc, Ixa	completed
48	Haddock	M	Faroe Plateau	ICES	Vb	completed
49	Herring	M	Gulf of Riga	n.a.	28	completed

50	Plaice	M	Celtic Sea	ICES	VIIf,g	completed
51	Saithe	M	Faroe Plateau	ICES	Vb	completed
52	Sole	M	Celtic Sea	ICES	VIIf,g	completed
53	Whiting	M	West of Scotland	ICES	VIa	completed
54	Arctic charr	F	Norway	n.a.	Lake Takvatn	completed
55	Brown trout	F	Norway	n.a.	Lake Takvatn	completed
56	Walleye	F		n.a.	Mille Lacs Lake	completed
57	Walleye	F		n.a.	Red Lake	completed

[1] Marine/Freshwater

- **Publications**
  - 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.

  - 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, in press.

  ➲ Outcome of ToR b.

  - 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 thrice in 2017: once physically for its annual meeting and twice remotely through video-conferencing for intersession 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 aims at providing a forum for exchanging and reviewing results of cutting edge research on adaptive changes of any phenotypic trait (life-history, phenology, migration, behaviour, 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).

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 the working group have 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 exploited 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).

Some members of WGEVO also studied more specifically 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 characteristics) 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 levelling off or reversing after the later imposition of fishing moratoria. These are compatible with theoretical expectations on fisheries-induced evolution. In contrast, the hypothesis of fisheries-induced evolution is not supported for females. These results have been submitted as a peer-reviewed article that is currently in press (Baulier *et al.* 2017; see full reference 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).

An application of the EvoIA framework to North Sea plaice was published last year (Mollet *et al.* 2016b; full reference in Section 4). There is no additional progress to report on this ToR this year.

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 44 exploited stocks until last year, and has been applied to 13 new stocks this year for a total of 57 stocks analysed (Table 1). Estimation of fisheries-induced selection pressures is currently in progress for a few additional stocks, but the WGEVO aims at consolidating the results of the selective pressure estimation by the end of this year. The statistical analysis of exogeneous (fishing intensity, fishing size-selectivity) and andogenous (stocks life-history characteristics) determinants of fisheries-induced selective pressures is currently in progress. A publication presenting these results is currently being drafted and to be submitted for peer-review by the end of next year.

Science Highlights

- The two peer-reviewed publications produced by WGEVO (Diaz Pauli *et al.* 2017, Baulier *et al.* 2017) present the following research highlights:
  - (i) 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).
  - (ii) 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 investment is more important for male reproductive success than expected in this lekking species (Baulier *et al.* 2017).
- 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 57 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 intercept), 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 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 (Annex 2, Figure A1), i.e. with increasing reproductive investment and with decreasing somatic investment, as well as with age and length at maturation (Annex 2, Figure A2 and A3, respectively).

(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.

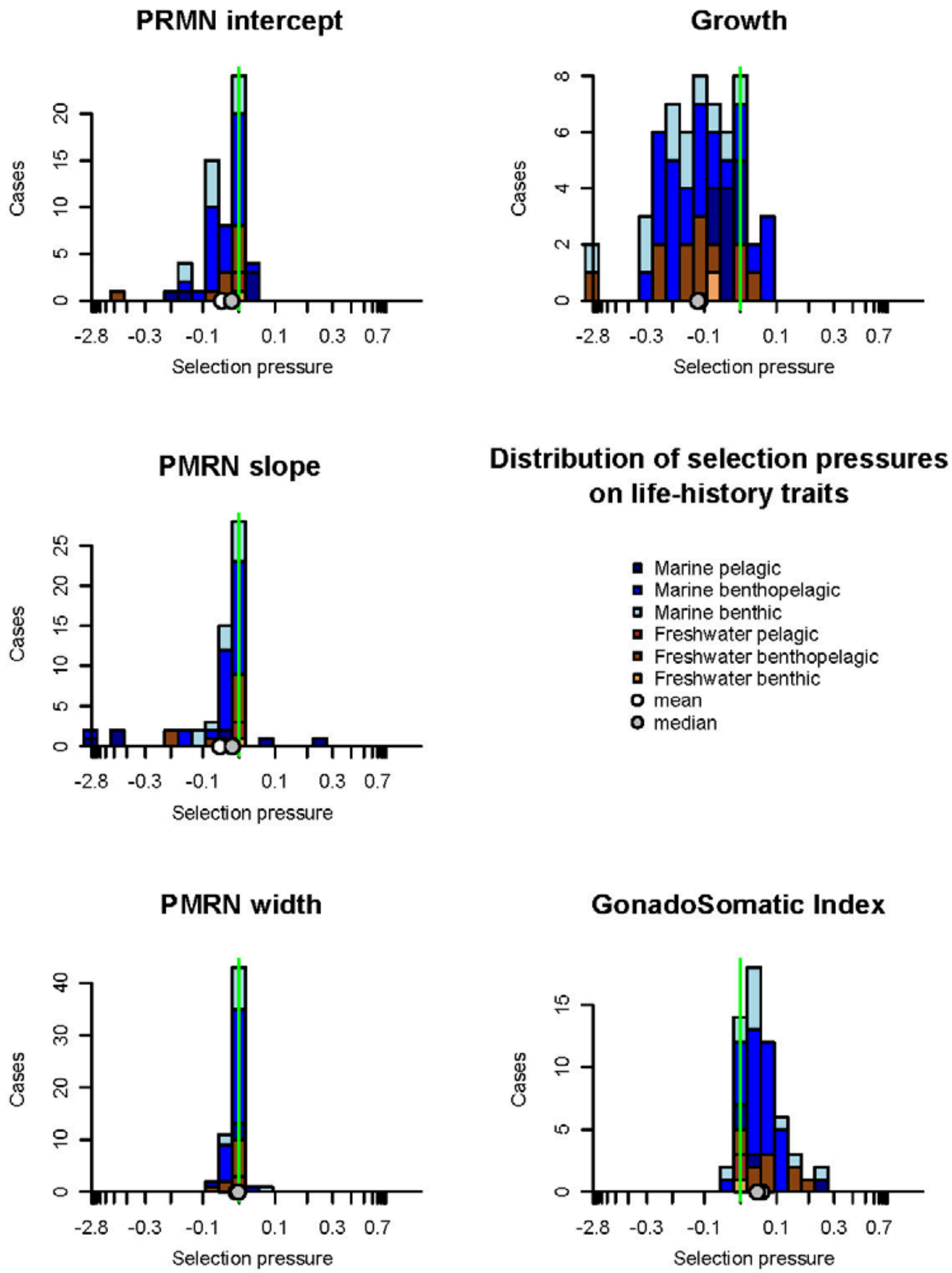

Figure 1. Frequency distributions of the standardized fisheries-induced selection pressures on the probabilistic maturation reaction norm (PMRN) intercepts, PMRN slopes, PMRN widths, juvenile growth potentials (Growth), and gonadosomatic indices (GSI) of 57 exploited fish stocks. Different colours indicate 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).

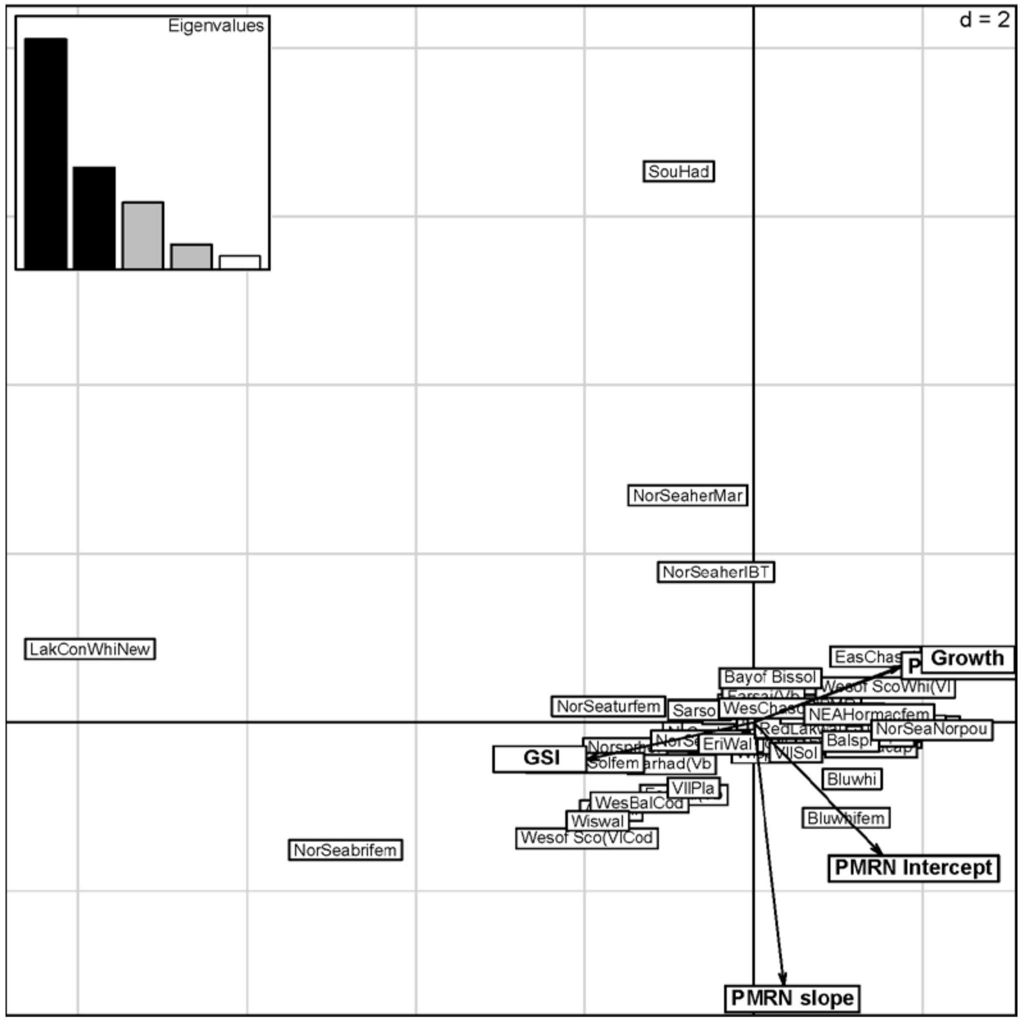

Figure 2. Principal components of the standardized fisheries-induced selection pressures on the life-history traits of 57 exploited fish stocks. Solitary labels represent the selection pressures on the five considered traits for each of the analysed stocks, while labelled arrows represent the resultant 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).

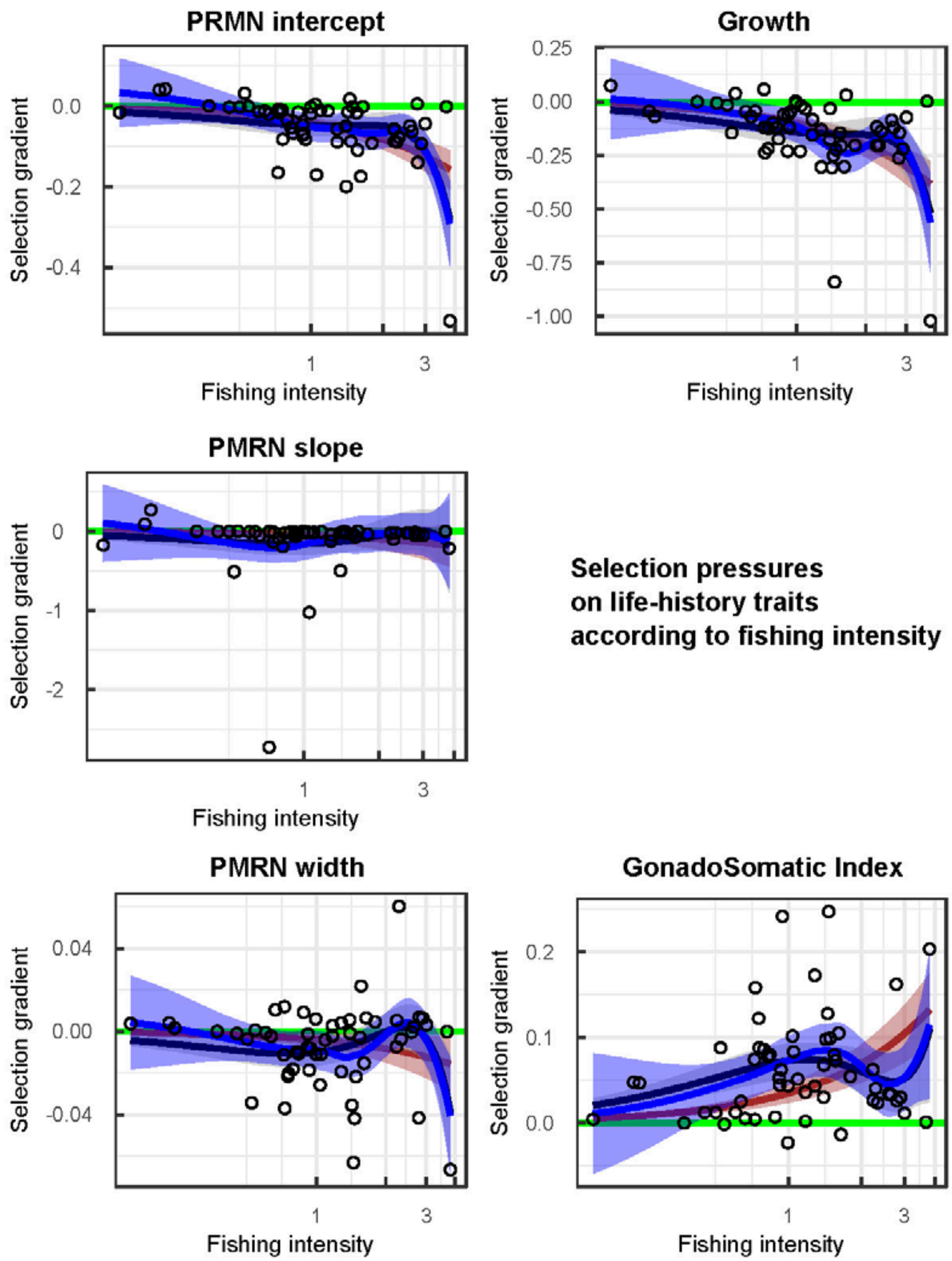

Figure 3. Standardized fisheries-induced selection pressures on the life-history traits of 57 exploited fish stocks according to fishing intensity (x-axis) computed as maximum fishing mortality rate relative to average maturation rate (obtained as the inverse of average maturation age). Note that the 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.

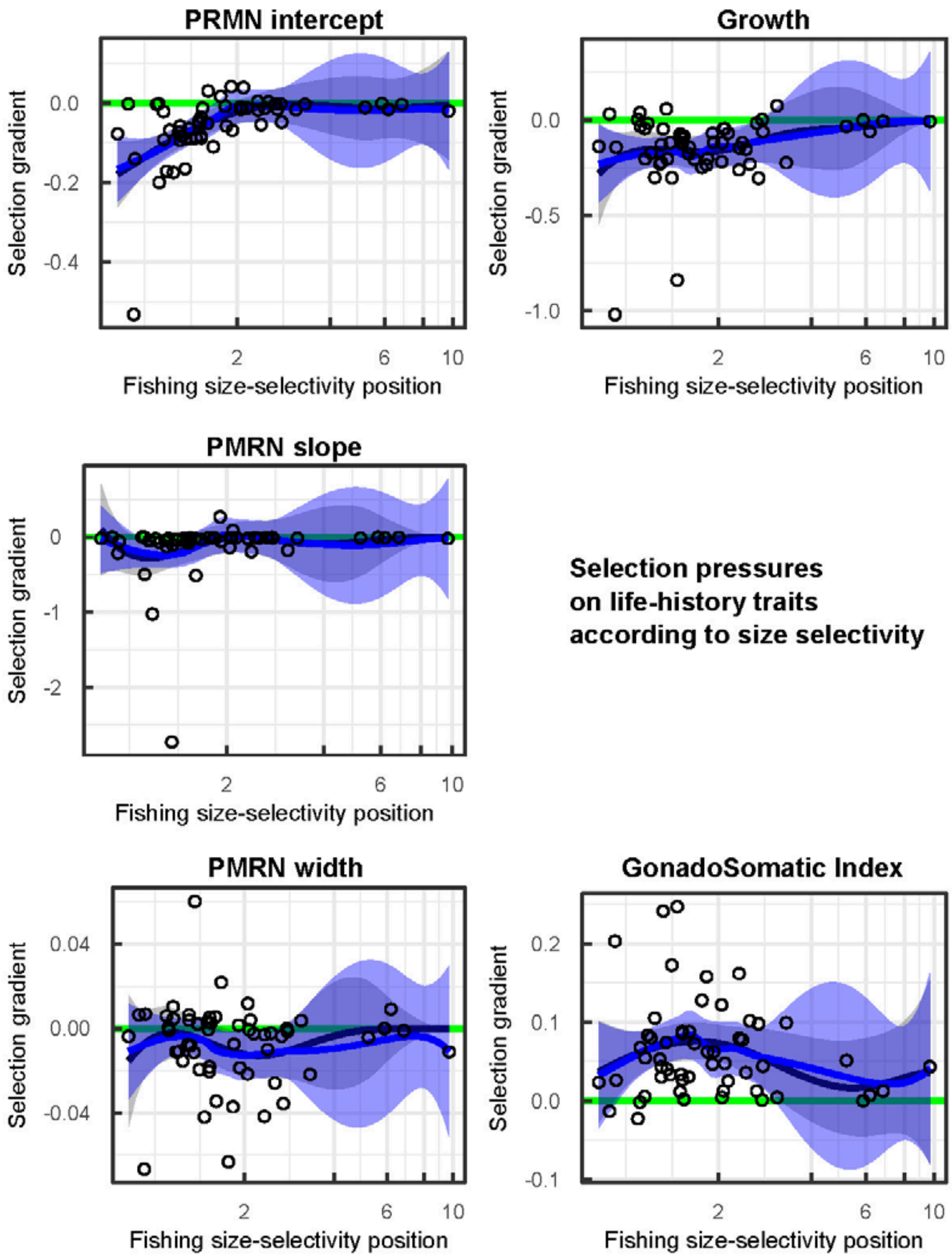

Figure 4. Standardized fisheries-induced selection pressures on the life-history traits of 53 exploited fish stocks exploited with a sigmoidal (or trawl-like) size-selectivity pattern according to fishing size-selectivity position (x-axis) computed as the length at which 50% of maximum fishing mortality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

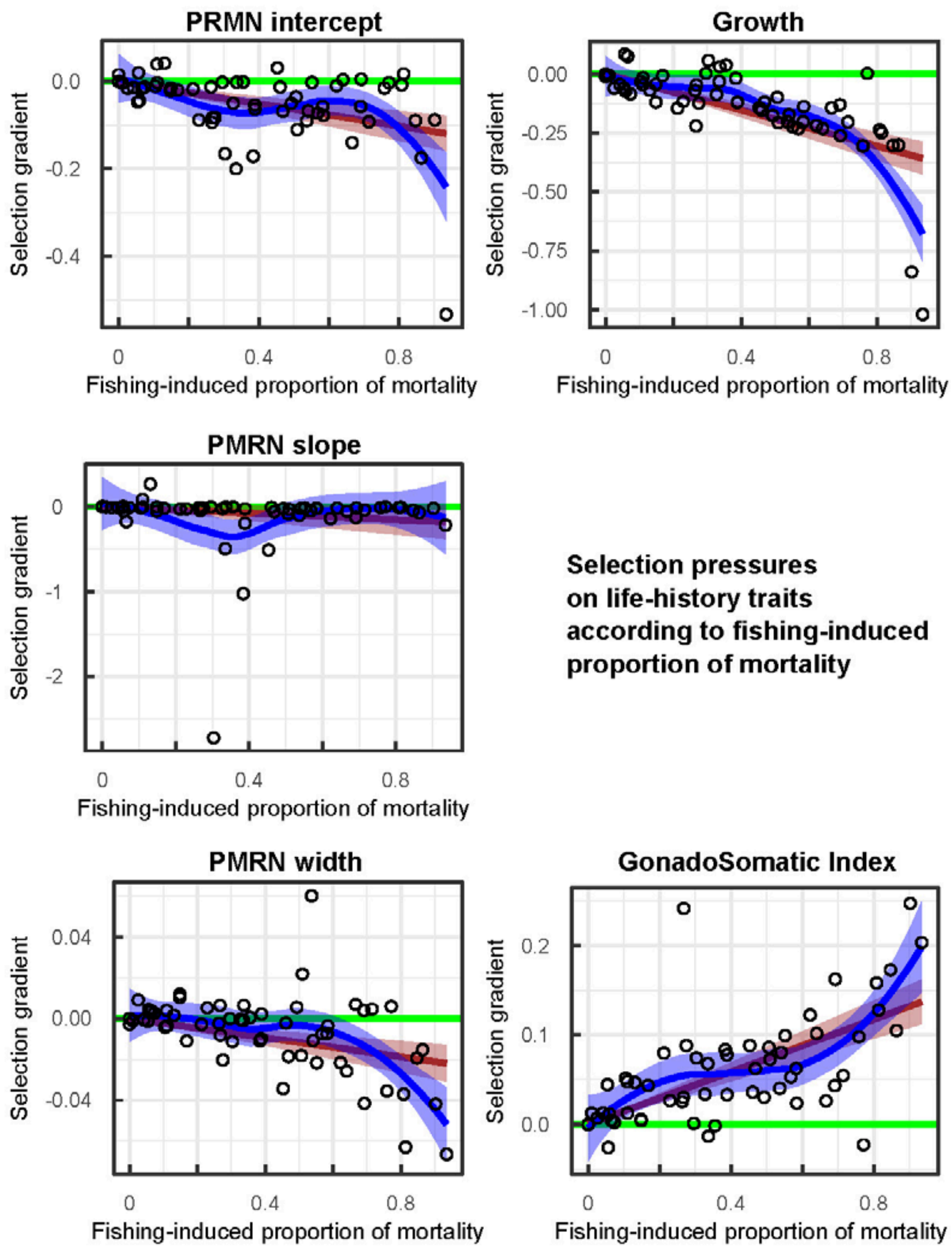

Figure 5. Standardized fisheries-induced selection pressures on the life-history traits of 57 exploited fish stocks according to fishing-induced proportion of mortality (x-axis) computed as *F/Z with z=F+M*. Green horizontal line indicates the absence of selection (i.e., a selection pressure of 0). The red line represents linear regression and the blue line approximation by a loess smoother.

6 Revisions to the work plan and justification

None.

7 Next meetings

The dates and venue for the annual meeting in year 3 (2018) will be decided between the members of the group at a later stage.

Annex 1: List of participants

Name	Address	Email
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Annex 2: Fisheries-induced selection pressures

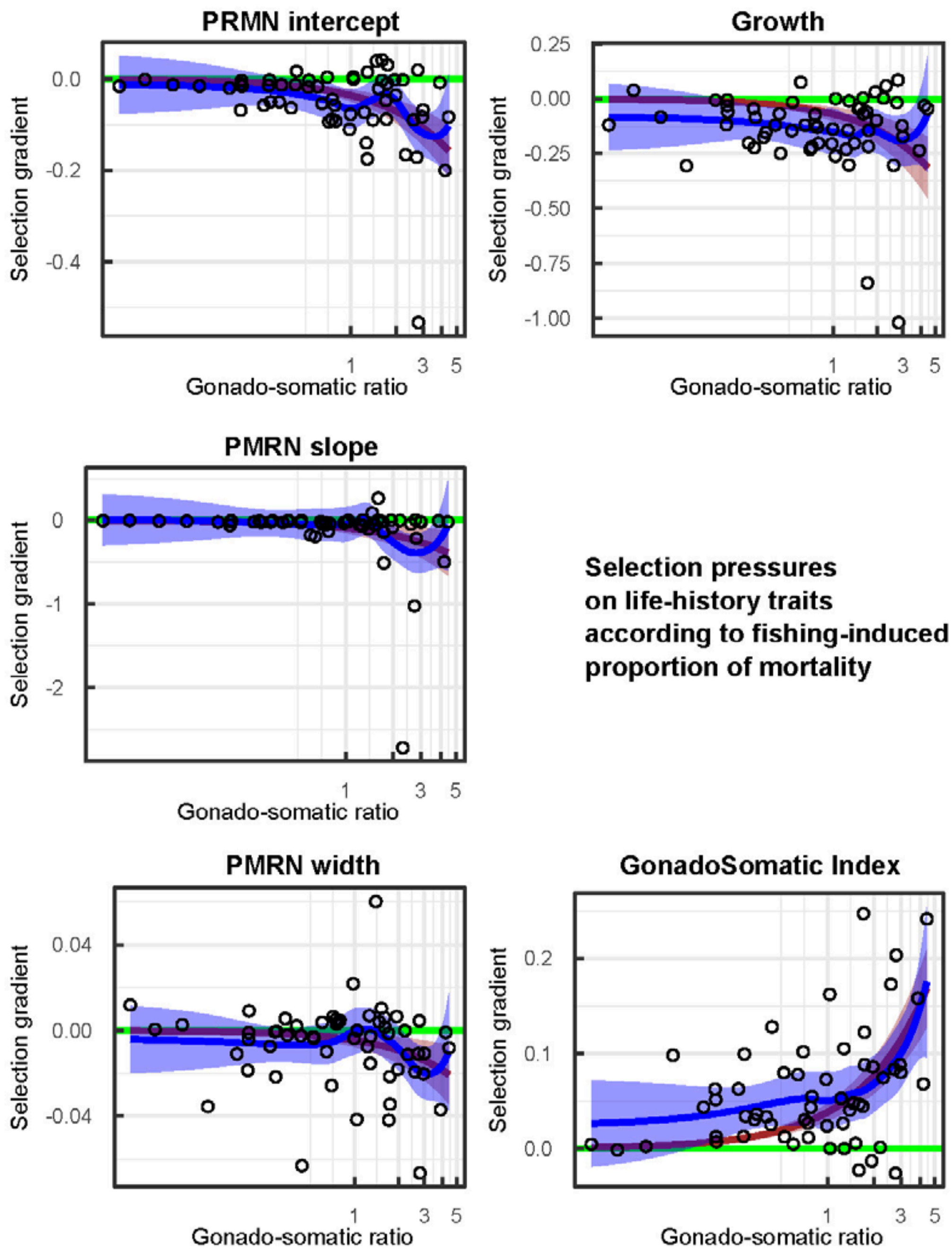

Figure A1. Standardized fisheries-induced selection pressures on the life-history traits of 57 exploited fish stocks according to gonado-somatic ratio (x-axis) i.e. the ratio of energy allocated to gonads against that allocated to soma during adulthood. Note that the x-axis is on logarithmic scale. Green 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.

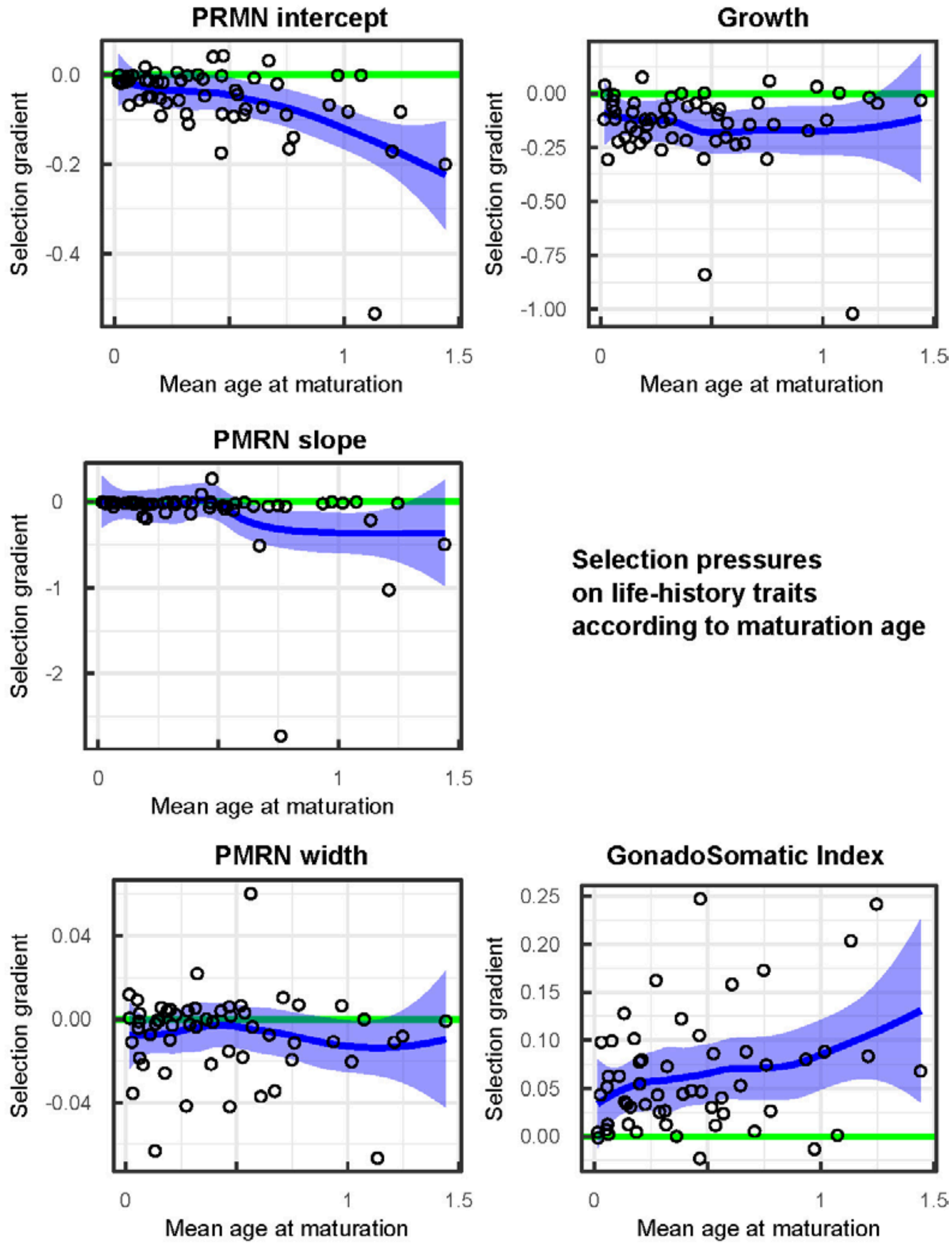

Figure A2. Standardized fisheries-induced selection pressures on the life-history traits of 57 exploited fish stocks according to mean age at maturation (x-axis) normalized by the age at which half of the maximum asymptotic length is reached. Note that the x-axis is on logarithmic scale. Green horizontal line indicates the absence of selection (i.e., a selection pressure of 0) and the blue line is an approximation by a loess smoother.

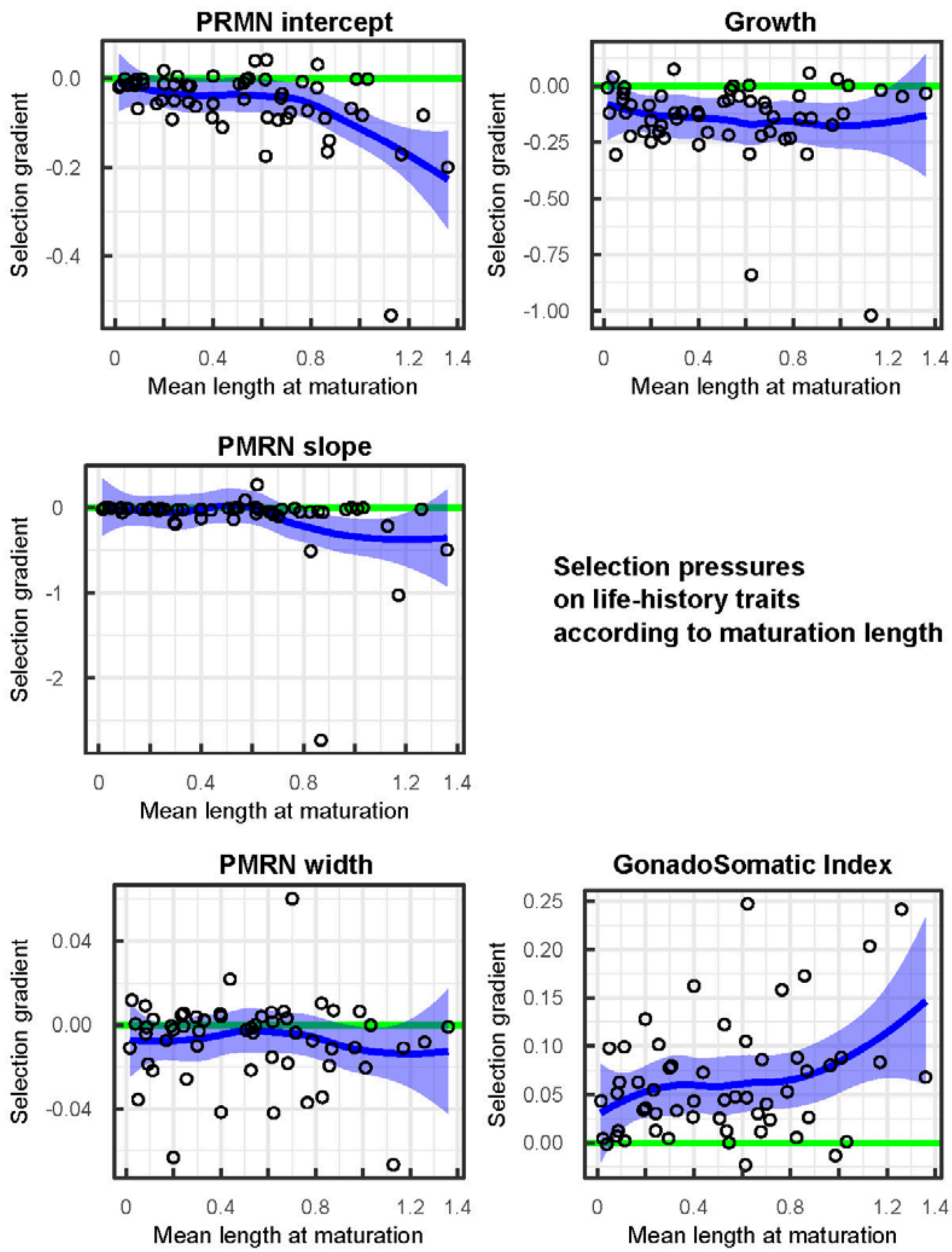

Figure A3. Standardized fisheries-induced selection pressures on the life-history traits of 57 exploited fish stocks mean length at maturation (x-axis) normalized by half the maximum asymptotic length. Note that the x-axis is on logarithmic scale. Green horizontal line indicates the absence of selection (i.e., a selection pressure of 0) and the blue line is an approximation by a loess smoother.