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

3-5 May 2011

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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) continues, on a more permanent basis, the work of the Study Group on Fisheries-Induced Adaptive Change (SGFIAC) that started in 2007. Together, these groups have set and unfolded the ICES agenda on fisheries-induced evolution (FIE). The Working Group's 2011 meeting held at ICES Headquarters from 3–5 May 2011, focused on (i) updates on new developments in the international research efforts on FIE; (ii) two manuscripts jointly prepared by the group's members, one on *Evolutionary Impact Assessments* (EvoIAs) and the other on the influence of FIE on reference points for fisheries management; (iii) development of simple tools for estimating fisheries-induced selection differentials from commonly available data; and (iv) application of these tools to key life history traits in a range of important stocks.

1 Opening and closing of the meeting

The Chairs opened the meeting on Tuesday, 3 May, at 09.00 and closed it on Thursday, 5 May, at 18.00.

2 Adoption of the agenda

The Terms of Reference for the Working Group on Fisheries-Induced Evolution (WGEVO) are listed below:

a) Provide a forum for international collaboration and exchange of emerging scientific insights on fisheries-induced adaptive changes;

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;

c) Develop the Evolutionary Impact Assessment framework and apply it to the specific challenges arising from fisheries-induced adaptive change and its consequences, including the following subtasks: (i) evaluate the impact of existing management measures and tools, such as minimum mesh and landing sizes, precautionary reference points, marine protected areas, and effort regulations, on fisheries-induced adaptive change; (ii) relate consequences of fisheries-induced adaptive change to stakeholder utilities and to current management objectives and evaluate possible more specific objectives for managing fisheries-induced adaptive change;

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.

WGEVO will report by 21 May 2011 for the attention of SCICOM and ACOM.

During this meeting, work on fisheries-induced evolution (FIE) was organized in four parts:

- Updates on new developments in FIE research
- Discussions of two draft manuscripts prepared by the working group on "*Evolutionary impact assessment: Accounting for evolutionary consequences of fishing in an ecosystem approach to fisheries management*" and "*Effects of FIE on reference points for fisheries management*"
- Development of R code for estimating fisheries-induced selection differentials
- Comparison of the resultant selection differentials across a range of exploited stocks

The corresponding developments are described in Sections 3 to 6 below.

3 Updates on new developments in FIE research

The meeting started with a presentation on new research developments related to FIE (Christensen and Andersen 2011). The title and co-authors are listed below, with the name of presenter being underlined:

- Asbjørn S. Christensen and Ken H. Andersen: *General classification of maturation reaction-norm shape from size-based processes*

4 Collaborative Working-Group papers

The work previously initiated by the Working Group, on developing a framework for evolutionary impact assessment, has resulted in the manuscript "*Evolutionary impact assessment: Accounting for evolutionary consequences of fishing in an ecosystem approach to fisheries management*". This manuscript describes evolutionary impact assessment (EvoIA) as a structured approach for assessing the evolutionary consequences of fishing and for evaluating the merits of alternative management options. EvoIA will (i) contribute to the ecosystem approach to fisheries management by clarifying how evolution alters stock properties and ecological relations, (ii) support the precautionary approach to fisheries management by addressing a previously overlooked source of uncertainty and risk, and (iii) help realize the Johannesburg summit's commitment to the restoration of sustain-able fisheries.

During the Working Group meeting, the manuscript was discussed. Accounting also for the comments by Working Group members who were unable to participate in this year's meeting, the core group will update the manuscript and circulate it for final consolidation. (The manuscript was submitted to *Fish and Fisheries* on July 20, 2011.)

The work previously initiated by the Working Group, on examining the effects of FIE on reference points for fisheries management, has resulted in the manuscript "*Can fisheries-induced evolution shift reference points for fisheries management?*" This manuscript shows that fisheries-management reference points are not static, but may change when a population's environment is changing or when the population itself is changing. FIE is one mechanism that can drive changes in population characteristics, leading to "shifting" reference points through two possible pathways: by changing the underlying biological processes and by leading to changes in the perception of a system. The former implies that "true" reference points are changing, whereas the latter implies that the yardstick used to quantify a system's status is changing. Unaccounted shifting of either kind means that reference points gradually lose their intended meaning. This can lead to increased precaution, which is safe, but may be costly. Shifting can also occur in the direction of danger, such that actual risks are higher than accepted. The qualitative analysis presented in the manuscript suggests that all commonly used reference points are susceptible to shifting through FIE, including the widely used limit and precautionary reference points for spawning-stock biomass (B_{lim} and B_{pa}) and fishing mortality (F_{lim} and F_{pa}). These findings call for increased awareness of FIE and highlight the value of specifying reference points based on adequately updated information, to capture changes in the biological processes that drive fish population dynamics.

During the Working Group meeting, the manuscript was discussed. Accounting also for comments by Working Group members who were unable to participate in this year's meeting, the core group will update the manuscript and circulate it for final consolidation. Submission to the *ICES Journal of Marine Science* is foreseen for September 2011.

5 Developing a tool for estimating selection differentials

Estimations of selection differentials allow fisheries scientists and managers to anticipate the direction of FIE and to assess the evolutionary vulnerability of specific traits and stocks to fishing. At the 2009 Study Group meeting, a workplan was agreed on to develop software for estimating selection differentials from data on life history traits (growth, maturation, and reproduction) and exploitation patterns (fishing mortality by age/length class) that are readily available for many stocks. Prior to the 2010 meeting, resultant R scripts were made available by Shuichi Matsumura and Mikko Heino. Selection differentials are estimated based on the Leslie-matrix approach (Arlinghaus et al. 2009; Matsumura et al. 2011) for four evolving traits affecting growth (alpha1), reproduction (GSI), and maturation (PMRN midpoint Lp50 and PMRN width; PMRN = probabilistic maturation reaction norm). The input parameters for this analysis can be estimated from weight-length-age-maturity data collected through surveys and/or commercial fisheries samples and from estimates of fishing mortality and natural mortality-at-age or size.

During the meeting, the R code was further developed, to improve its performance and make it more generic.

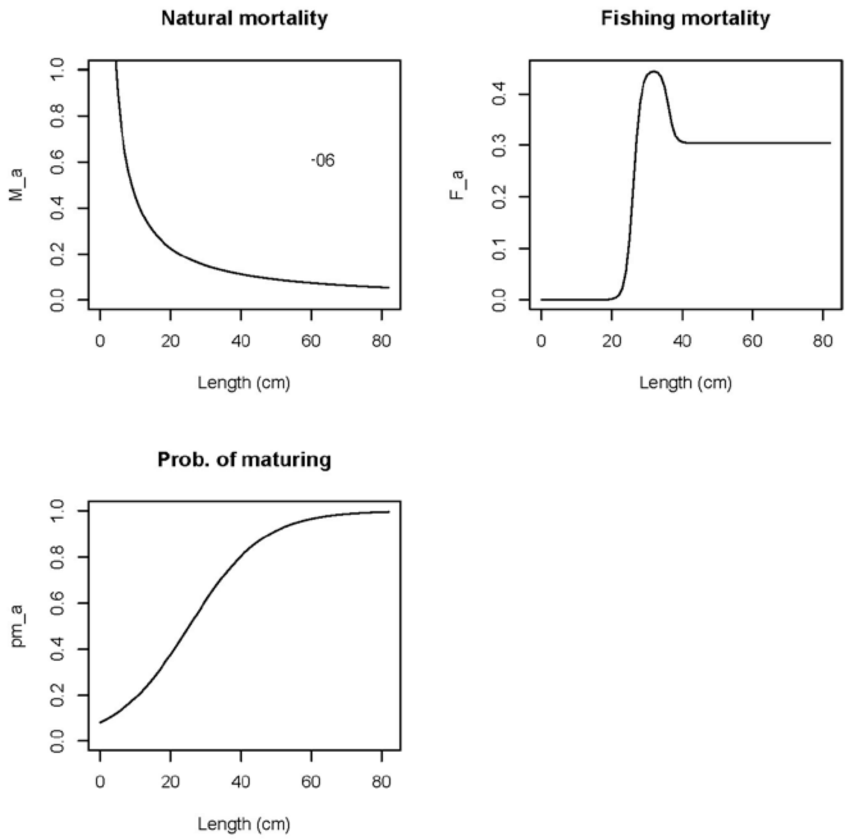


Figure 1. Relationships between size and natural mortality, fishing mortality, and maturation probability used to estimate the selection differentials for eastern Channel sole.

6 Estimating fisheries-induced selection differentials

This section presents results of a preliminary analysis of fisheries-induced selection differentials in female eastern Channel sole for the period 1995-1999. Figure 1 shows the current exploitation pattern as estimated by the recent ICES stock assessment, as well as the assumed relationship between the rate of natural mortality and size, and the observed maturity ogive. The exploitation pattern obtained from the age-based assessments was converted to a size-based relationship by plotting F-at age against mean size-at age. The exploitation shows a peak at intermediate sizes. No trade-off between growth and mortality was assumed. Selection differentials were estimated for the situation with fishing and with no fishing.

The preliminary results show that fishing selects for an increase in the energy acquisition rate determining growth (alpha1), an increase in reproductive investment (GSI), a decrease in the PMRN midpoint Lp50, and an increase in the PMRN width. The strength of selection is strongest for growth (standardized selection differential S = 0.25). However, when compared to the selection differentials for the case with no fishing, the analysis suggest that fishing selects for a reduction in growth (ΔSD = -0.948), an increase in reproduction (ΔSD = 0.0698), a decrease in the PMRN midpoint Lp50 (ΔSD = -0.0558), and an increase in PMRN width (ΔSD = 0.0223). The results for five other ICES stocks, assuming a similar exponent of the relation between natural mortality and size, are in broad agreement with those for eastern Channel sole (Table 1).

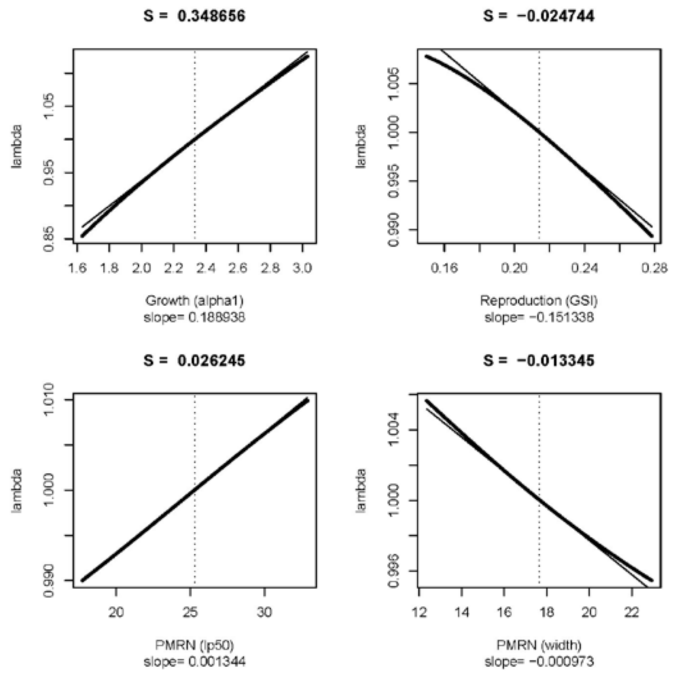
Two relationships are particularly difficult to establish based on the available data: the growth-mortality trade-off and the relationship between natural mortality and size. To assess the sensitivity of results to uncertainty in these relationships, a sensitivity analysis was carried out in which (1) the allometric exponent of the relationship between natural mortality and size and (2) the strength of the growth-mortality trade-off were varied. The exponent was allowed to range from zero (no size dependence) to 3 (unrealistically strong size dependence), whereas the trade-off had two levels, absent and weak. The results (Table 2) show that the estimated selection differentials are not sensitive to these parameters, as long as the allometric exponent is not exceedingly large.

Based on these explorations using data from six ICES stocks, the underlying R scripts will be made available to all WGEVO members with the aim of applying these tools to a wider range of important stocks. The eventual product of this project will be a scientific paper, again envisaged to be written with suitable collective authorship.

Table 1. Summary of the exploratory analysis of fisheries-induced selection differentials for six ICES stocks.

	Difference in selection differential (ΔSD) between fishing and no fishing			
	Growth	Reproduction	PMRN Lp50	PMRN width
Eastern Channel sole	-0.0948	0.0698	-0.0558	0.0223
North Sea sole	-0.2727	0.0226	-0.0695	0.0162
North Sea plaice	-0.0767	0.0000	-0.0062	0.0009
North Sea turbot	-0.0829	0.0029	-0.0084	0.0005
North Sea brill	-0.1832	0.0016	-0.0040	0.0000
North Sea herring	-0.0702	0.0050	-0.0248	0.0009
	Selection differential (SD) with fishing			
Eastern Channel sole	0.2538	0.0451	-0.0296	0.0090
North Sea sole	0.4978	0.0400	-0.1230	0.0135
North Sea plaice	0.6603	0.0165	-0.0635	-0.0005
North Sea turbot	0.4266	-0.0074	-0.0254	0.0010
North Sea brill	0.3033	-0.0287	-0.0103	0.0000
North Sea herring	0.2591	0.0184	-0.0696	0.0004
	Selection differential (SD) with no fishing			
Eastern Channel sole	0.3486	-0.0247	0.0262	-0.0133
North Sea sole	0.7705	0.0174	-0.0534	-0.0027
North Sea plaice	0.7370	0.0165	-0.0573	-0.0014
North Sea turbot	0.5095	-0.0103	-0.0171	0.0005
North Sea brill	0.4866	-0.0304	-0.0063	0.0000
North Sea herring	0.3292	0.0134	-0.0448	-0.0005

With fishing:



Without fishing:

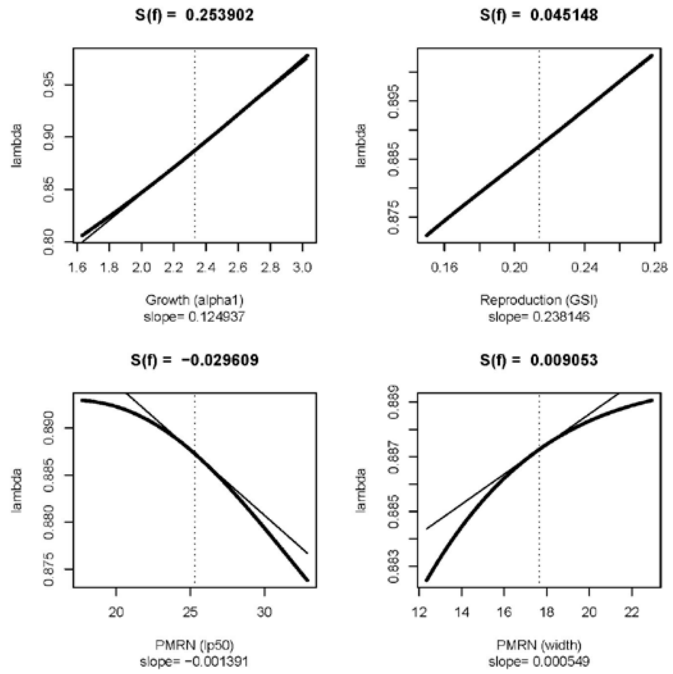


Figure 2. Standardized selection differentials (S) and influence of variation in life history traits for growth (alpha1), reproduction (GSI), and maturation (PMRN midpoint Lp50 and PMRN width) on population growth ratio (lambda) in eastern Channel sole. The upper four panels show the effects of the current fishing regime, while the lower four panels show the situation with no fishing. Dotted vertical lines indicate the population means of trait, used for calculating the selection differentials.

Table 2. Sensitivity analysis for North Sea herring with respect to the allometric exponent b of the natural-mortality-length relationship and the strength G of the growth-mortality trade-off.

North Sea herring	Difference in selection differential (ΔSD) between fishing and no fishing			
	Growth	Reproduction	PMRN Lp50	PMRN width
b = 0, G = 0	-0.0733	0.0054	-0.0270	0.0011
b = 0.75, G = 0	-0.0717	0.0051	-0.0253	0.0010
b = 1.5, G = 0	-0.0637	0.0048	-0.0238	0.0009
b = 3, G = 0	0.0873	0.0042	-0.0210	0.0006
b = 0, G = 0.05	-0.0725	0.0054	-0.0270	0.0011
b = 0.75, G = 0.05	-0.0710	0.0051	-0.0253	0.0010
b = 1.5, G = 0.05	-0.0631	0.0048	-0.0238	0.0009
b = 3, G = 0.05	0.0879	0.0042	-0.0210	0.0006
	Selection differential (SD) with fishing			
b = 0, G = 0	0.1622	0.0204	-0.0773	0.0006
b = 0.75, G = 0	0.2223	0.0188	-0.0714	0.0005
b = 1.5, G = 0	0.3918	0.0175	-0.0663	0.0003
b = 3, G = 0	3.0522	0.0154	-0.0580	-0.0001
b = 0, G = 0.05	-0.1330	0.0204	-0.0773	0.0006
b = 0.75, G = 0.05	-0.0728	0.0188	-0.0714	0.0005
b = 1.5, G = 0.05	0.0980	0.0175	-0.0663	0.0003
b = 3, G = 0.05	2.8000	0.0154	-0.0580	-0.0001
	Selection differential (SD) with no fishing			
b = 0, G = 0	0.2355	0.0149	-0.0503	-0.0005
b = 0.75, G = 0	0.2940	0.0137	-0.0460	-0.0005
b = 1.5, G = 0	0.4555	0.0127	-0.0425	-0.0006
b = 3, G = 0	2.9650	0.0111	-0.0370	-0.0008
b = 0, G = 0.05	-0.0605	0.0149	-0.0503	-0.0005
b = 0.75, G = 0.05	-0.0018	0.0137	-0.0460	-0.0005
b = 1.5, G = 0.05	0.1611	0.0127	-0.0425	-0.0006
b = 3, G = 0.05	2.7121	0.0111	-0.0370	-0.0008

7 Future of the Working Group

The Working Group recognized that good progress in addressing the terms of reference has been made and that significant challenges in bridging the gap towards the management of concrete fish stocks remain. The current terms of reference are an adequate reflection of the ambitions of the group and are clearly linked with the science plan of ICES, in particular with the themes *Impacts of fishing on marine ecosystems* and *Development of options for sustainable use of ecosystems*.

8 References

Arlinghaus, R., Matsumura, S., Dieckmann, U. 2009. Quantifying selection differentials caused by recreational fishing: development of modeling framework and application to reproductive investment in pike (*Esox lucius*). Evolutionary Applications, 2: 335–355.

Christensen, A.S., Andersen, K. H. 2011. General classification of maturation reaction-norm shape from size-based processes. Bulletin of Mathematical Biology, 73: 1004–1027.

Matsumura, S., Arlinghaus, R., and Dieckmann, U. 2011. Assessing evolutionary consequences of size-selective recreational fishing on multiple life-history traits, with an application to northern pike (*Esox lucius*). Evolutionary Ecology, 25: 711–735.

Annex 1: List of participants

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Annex 2: WGEVO terms of reference for the next meeting

The Working Group on Fisheries-Induced Evolution (WGEVO), chaired by Mikko Heino, Norway, Norway, Ulf Dieckmann, Austria, and Adrian D. Rijnsdorp, The Netherlands, will meet in Copenhagen during 7–11 May 2012 to:

a) Provide a forum for international collaboration and exchange of emerging scientific insights on fisheries-induced adaptive changes;

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;

c) Develop the Evolutionary Impact Assessment framework and apply it to the specific challenges arising from fisheries-induced adaptive change and its consequences, including the following subtasks: (i) evaluate the impact of existing management measures and tools, such as minimum mesh and landing sizes, precautionary reference points, marine protected areas, and effort regulations, on fisheries-induced adaptive change; (ii) relate consequences of fisheries-induced adaptive change to stakeholder utilities and to current management objectives and evaluate possible more specific objectives for managing fisheries-induced adaptive change;

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.

WGEVO will report by 31 May 2012 for the attention of SCICOM and ACOM.

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 future management. Such advice is needed in relation with the precautionary approach, the ecosystem approach, biodiversity conservation, and the evaluation of risk and uncertainty.

Scientific justification and relation to action plan	Linkages exist with all three 'Thematic areas' in the ICES Science Plan 2009–2013: Understanding Ecosystem Functioning (research topics 'Fish life history information in support of EAM' and 'Biodiversity and the health of marine ecosystems'). Understanding of Interactions of Human Activities with Ecosystems (research topic 'Impacts of fishing on marine ecosystems'). Development of Options for Sustainable Use of Ecosystems (research topic 'Marine living resource management tools'). Term of Reference a) An international forum transcending individual research projects and geographically limited activities has proven very valuable, as investigations of fisheries-induced adaptive changes have broad geographic relevance and require bringing together a wide range of expertise. Term of Reference b) Significant research efforts are currently being invested within this area in several countries. The subject area will therefore benefit from a continual review of the progress being made, a joint evaluation of results obtained, and a free exchange of information for guiding future resarch and management. Term of Reference c) The new framework of Evolutionary Impact Assessments (EvoIAs) introduced by SGFIAC provides an integrative platform for assessing the consequences of fisheries-induced adapative changes and for evaluating how these are influenced by current and alternative management measures. WGEVO is in an excellent position to develop this framework further and to apply it to selected case studies. Term of Reference d) A basic set of statistical and modelling tools for dealing with fisheries-induced adaptive change are now available, but these need to be developed further for greater flexibility, transparency, and ease of use. This includes establishing quality-controlled packages of software and scripts, linkage to other standardized platforms such as the Fisheries Library in R (FLR), and making selected tools available through the web.
Resource requirements	The research actibvities providing input to WGEVO are ongoing, and corresponding resources have been committed by the engaged institutions. The resources for convening the annual WGEVO meeting are negligible.
Participants	WGEVO is normally attended by 10–20 members and guests.
Secretariat facilities	None.
Financial:	No financial implications.
Linkages to advisory committees	ACOM
Linkages to other committees or groups	For management implications: Working Group on Maritime Systems (WGMARS). For more fundamental aspects: Working Group on the Application of Genetics in Fisheries and Mariculture (WGAGFM); Working Group on Ecosystem Effects of Fishing Activities (WGECO).
Linkages to other organizations	None.