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Report of the Study Group on Fisheries Induced Adaptive Change (SGFIAC)

31 March–2 April 2009

ICES Headquarters, Copenhagen

ICES International Council for the Exploration of the Sea

CIEM Conseil International pour l'Exploration de la Mer

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Contents

Executive summary

The Study Group on Fisheries Induced Adaptive Change (SGFIAC) 2009 meeting focused on (i) updates on new developments in research on fisheries-induced evolution (FIE), (ii) methods for estimating selection differentials created by FIE, (iii) computational tools for dealing with FIE, in particular how to link the *Fisheries Library in R* (FLR) to eco-genetic models, (iv) discussions about two manuscripts initiated during the group's 2008 meeting and jointly prepared by the group's members intersessionally, one on *Evolutionary Impact Assessments* (EvoIAs) and the other on the influence of FIE on reference points for fishery management, and (v) review the evidence for fisheries-induced evolutionary change in the OSPAR region. Following the discussions on (ii), the Study Group agreed to initiate a joint project on (a) developing simple tools for estimating from commonly available data fisheries-induced selection differentials and (b) applying 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, 31 March, at 09.00 and closed it on Thursday, 2 April, at 18.00.

2 Adoption of the agenda

The Terms of Reference for the Study Group on Fisheries Induced Adaptive Change (SGFIAC) are listed below. Four items refer to medium-term tasks (a-d) and a new item had been specifically added for this year (e):

a) 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, including previous work by WGAGFM and WGECO;

b) 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;

c) develop scientific and methodological tools to monitor and respond appropriately to risks to biodiversity and sustainable exploitation posed by fisheries-induced adaptive change;

d) relate consequences of fisheries-induced adaptive change to current management objectives and evaluate possible more specific objectives for managing fisheries-induced adaptive change;

e) review the evidence of fisheries-induced adaptive change in commercially exploited fish stocks in the OSPAR area in relation to the Quality Status Report (QSR) 2010.

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

- Updates on new developments in FIE research
- Selection differentials underlying FIE
- Computational tools for dealing with FIE
- Effects of FIE on reference points for fishery management
- Evolutionary impact assessment
- OSPAR Quality Status Report 2010 and FIE

The corresponding developments are described in Sections 3 to 8 below. A more detailed agenda of the meeting is provided in Annex 2.

3 Updates on new developments in FIE research

The article "Managing Evolving Fish Stocks," originating from the group's first meeting in 2007 and published in November 2007 as a Policy Forum article in the journal *Science* (Jørgensen *et al*., 2007), triggered a lively debate that was published in *Science* in April 2008 (Browman *et al*., 2008; Kuparinen and Merilä, 2008; Jørgensen *et al*., 2008).

During this meeting, members/participants gave ten short presentations on new research developments related to FIE. Titles and co-authors are listed below, with the names of presenters being underlined:

- Lodewijk van Walraven, Fabian Mollet, Cindy van Damme and Adriaan Rijnsdorp: Fisheries-induced evolution in growth, maturation and reproductive investment of the sexually dimorphic North Sea plaice
- Anne Maria Eikeset, Erin S. Dunlop, Mikko Heino, Olav Rune Godø, Nils Chr. Stenseth and Ulf Dieckmann: Eco-genetic model of northeast Arctic cod
- Christian Jørgensen, Bruno Ernande and Øyvind Fiksen: Size-dependent harvest in northeast Arctic cod
- Davnah Urbach, Mikko Heino, Minho Kang, Suam Kim and Ulf Dieckmann: Estimation of growth, survival, and maturation in Korean chum salmon
- Fabian Mollet, Katja Enberg, David Boukal, Jan Jaap Poos, Adriaan Rijnsdorp and Ulf Dieckmann: Eco-genetic model for flatfish
- Ingrid Wathne: What can Daphnia teach us about FIE?
- Katja Enberg, Christian Jørgensen, Erin S. Dunlop, Mikko Heino and Ulf Dieckmann: Implications of fisheries-induced evolution for stock rebuilding and recovery
- Lise Marty, Bruno Ernande and Marie-Joëlle Rochet: Maturation of North Sea gadoids
- Loïc Baulier, Mikko Heino, M. Joanne Morgan, George Lilly and Ulf Dieckmann: Have cod stocks off Newfoundland adapted to fishing pressure by increasing their reproductive investment?
- Ulf Dieckmann and Mikko Heino: Prospective and retrospective PMRNs

4 Selection differentials underlying FIE

Estimation of selection differentials allows fishery scientists and managers to anticipate the direction of FIE and to assess the evolutionary vulnerability of specific traits and stocks to fishing. The group therefore reviewed alternative methods for estimating selection differentials and discussed which of these methods could be applied to commonly available stock data.

Group participants gave three presentations that served as introductions to this agenda item. Titles and co-authors are listed below, with the names of presenters being underlined:

- Shuichi Matsumura, Robert Arlinghaus and Ulf Dieckmann: *Standardization of selection differentials*
- Shuichi Matsumura, Robert Arlinghaus and Ulf Dieckmann: *Quantifying selection strength on multiple life-history traits in pike*
- David Boukal, Erin S. Dunlop, Mikko Heino and Ulf Dieckmann: *Gear selectivity and life-history evolution*

The group agreed to initiate a joint project on (a) developing simple tools for estimating from commonly available data fisheries-induced selection differentials and (b) applying these tools to key life-history traits in a range of important stocks.

5 Computational tools for dealing with FIE

In recent years, considerable effort has been invested into integrating the computational tools fishery scientists are relying on into a single framework, so that different tools can benefit from common data formats and other forms of linkage. A prominent development along these lines is the FLR framework (Fisheries Library for R; Kell *et al.*, 2008). This framework includes not only conventional stock assessment tools, but also modules covering the whole fishery system such that the evaluation and development of management strategies is possible.

Jan Jaap Poos explained how an eco-genetic model can be incorporated in the FLR framework and discussed the advantages and disadvantages. In the short-term, the advantage is that it facilitates the archiving of the different runs and their specific parameters settings, as well as the use of the multitude of tools already available in FLR to analyse and plot the results. A comparison of the processing time of the eco-genetic model ran independently and the one integrated to FLR showed comparable runtime. The processing time of the eco-genetic studies may be easily reduced by using parallel processing of several scenarios within FLR. On the longer term, combining eco-genetic models with other models in FLR will allow easier access to eco-genetic modelling, and integrated evaluation of management strategies, where the process knowledge of fishery and their management can be combined with the evolutionary dynamics of stocks.

6 Effects of FIE on reference points for fishery management

At its meeting in 2008, the Study Group initiated a joint project on the effects of FIE on reference points for fishery management. Following discussions during the meeting and the drafting of an outline right thereafter, the main sections were written and commented on by group members and consolidated by a core group. An advanced draft of the resulting manuscript, currently entitled *Can fisheries-induced evolution shift reference points for fisheries management?*, was circulated among the participants and discussed in plenum. The core group will update the draft following these discussions and circulate it for further comments and consolidation. Submission is foreseen within the next few months, presumably to the *ICES Journal of Marine Science*.

The results described in the manuscript suggest that reference points are influenced by FIE. Whether these changes are positive or negative from a sustainability perspective depends on the reference point, the nature of FIE, and how regularly biological information on a stock is updated. Cases where FIE could lead to management that is less precautionary than intended are must be of concern to fishery managers. The group encourages more detailed follow-up studies on how large these effects are in particular cases.

7 Evolutionary impact assessment

At its meeting in 2008, the Study Group initiated another joint project on the specification of a framework for evolutionary impact assessment. Following discussions during the meeting and the drafting of an outline right thereafter, the main sections were written and commented on by group members and consolidated by a core group. An advanced draft of the resulting manuscript, currently entitled *Evolutionary impact assessment: Accounting for evolutionary consequences of fishing in an ecosystem approach to fishery management*, was circulated among the participants and discussed in plenum. The core group will update the draft following these discussions and circulate it for further comments and consolidation. Submission is foreseen within the next few months.

Evolutionary impact assessment (EvoIA) is an integrated set of methods for assessing the evolutionary consequences of fishing and for evaluating the merits of alternative management options. EvoIAs (i) contribute to the ecosystem approach to fishery management by clarifying how evolution alters stock properties and ecological relations, (ii) support the precautionary approach to fishery management by addressing a previously overlooked source of uncertainty and risk, and (iii) help realize the Johannesburg summit's commitment to the restoration of sustainable fishery by assisting fishery managers to cope with the evolutionary implications of fishing. The group encourages application of the EvoIA approach to selected case studies.

8 OSPAR Quality Status Report 2010 and FIE

Fisheries may result in changes in the phenotypic characteristics of individuals in a population, caused by fishing and reflecting both genetic changes and changes as a result of adaptive phenotypic plasticity. Evidence for fisheries-induced evolution was reviewed by the study group in 2007 (ICES, 2007) and resulted in the Science Policy Forum article (Jørgensen *et al.*, 2007). Other recent reviews are given in Kuparinen and Merilä (2007), Allendorf *et al.* (2008), Heino and Dieckmann (2008) and Hutchings and Fraser (2008).

Table 8.1 presents an update of this review. The review is restricted to those studies that have attempted to disentangle genetic changes from phenotypic plasticity in life history traits that are relevant to the productivity of the fish stocks: onset of maturation, reproductive investment, and somatic growth. The evidence was scored into one of three classes: observed change were likely as a consequence of evolutionary change (E); observed change likely as a consequence of phenotypic plasticity (PP); causes unclear (Inconclusive). The review comprises both stocks within and outside the OSPAR area.

The review shows that trends towards maturation at an earlier age and/or a smaller size have been observed in a wide variety of fish stocks in a wide variety of ecosystems and are consistent with the theoretical expectations. For the large majority of the studies, the observed changes were likely as a result of a fisheries-induced adaptive change. For life history traits such as reproductive investment and somatic growth rate, there is positive evidence suggesting fisheries-induced change, although the number of studies is relatively few.

Within the OSPAR area, evidence of an evolutionary change in maturation was obtained for three of the five species or populations studied: cod in the North Sea, west of Scotland, and in the Baltic (Yoneda and Wright, 2005; Vainikka *et al.*, 2009), and plaice and sole in the North Sea (Grift *et al.*, 2003, 2007; Kraak 2007; Mollet *et al.*, 2007), all showed a consistent decline in the size and age at maturation that could not be explained from a phenotypic response to a change in growth rate or temperature alone. The evidence of herring suggested that the changes were mainly because of phenotypic plasticity (Engelhard *et al.*, 2004), whereas the changes in Atlantic salmon were inconclusive (Kuparinen *et al.*, 2009). The lack of response in herring is consistent with the selection of the fisheries mainly targeting adult herring. For three species changes in reproductive investment were analysed. In all three, an increase was observed that was consistent with an evolutionary change and that could not solely be explained from the phenotypic plasticity (Yoneda and Wright, 2004; Rijnsdorp *et* *al.*, 2005; Wright, 2005). No species in the OSPAR area have been studied for a fisheries-induced genetic change in growth rate.

Table 8.1. Empirical studies of fisheries-induced evolutionary changes in maturation (1a), reproductive investment (1b) and growth (1c).

1A) TREND TOWARDS MATURATION AT EARLIER AGE AND/OR SMALLER SIZE				
AREA	OSPAR AREA	PERIOD	CONCLUSION	SOURCE
American plaice – *Hippoglossoides platessoides*				
Labrador and NE Newfoundland		1973 – 1999	E	Barot, Heino, Morgan, Dieckmann, ICES J. Mar. Sci. 62, 56 (2005).
Grand Bank		1969 – 2000	E	Barot, Heino, Morgan, Dieckmann, ICES J. Mar. Sci. 62, 56 (2005).
St. Pierre Bank		1972 – 1999	E	Barot, Heino, Morgan, Dieckmann, ICES J. Mar. Sci. 62, 56 (2005).
Atlantic cod – *Gadus morhua*				
Northeast Arctic		1932 – 1998	E	Heino, Dieckmann, Godø, ICES CM 2002 Y, 14 (2002).
Georges Bank		1970 – 1998	E	Barot, Heino, O'Brien, Dieckmann, Ecol. Appl. 14, 1257 (2004).
Gulf of Maine		1970 – 1998	E	Barot, Heino, O'Brien, Dieckmann, Ecol. Appl. 14, 1257 (2004).
Northern		(1977 – 1981 – 2002	E	Olsen *et al.*, Nature 428, 932 (2004).
Southern Grand Bank		1971 – 2002	E	Olsen *et al.*, Can. J. Fish. Aquat. Sci. 62, 811 (2005).
St. Pierre Bank		1972 – 2002	E	Olsen *et al.*, Can. J. Fish. Aquat. Sci. 62, 811 (2005).
North Sea and West of Scotland	OSPAR	1969 – 1970, 2002 – 2003	E	Yoneda, Wright, Mar. Ecol. Progr. Ser. 276, 237 (2004).
Baltic	OSPAR	1984 – 1997	E	Cardinale, Modin, Fish. Res. 41, 285 (1999).
Baltic	OSPAR	1989 – 2003	E	Vainikka, Gårdmark, Bland, Hjelm, ICES J Mar Sci 66: 248–257 (2009)
Atlantic herring – *Clupea harengus**				
Norwegian spring-spawning	OSPAR	1935 – 2000	PP	Engelhard, Heino, Mar. Ecol. Progr. Ser. 272, 245 (2004).
Atlantic salmon – *Salmo salar*				
Goodbout River, Quebec		1859 – 1983	E	Bielak, Power, Can. J. Fish. Aquat. Sci. 43, 281 (1986).
Atlantic	OSPAR		Inconclusive	Kuparinen, Garcia de Leaniz, Consuegra, Merila, Mar. Ecol. Progr. Ser. 376: 245–252 (2009)
Brook trout – *Salvelinus fontinalis*				
17 Canadian lakes		1984, 1999, comparative	E	Magnan, Proulx, Plante, Can. J. Fish. Aquat. Sci. 62, 747 (2005).
Chinook salmon – *Oncorhynchus tschawytscha*				

1A) TREND TOWARDS MATURATION AT EARLIER AGE AND/OR SMALLER SIZE				
AREA	OSPAR AREA	PERIOD	CONCLUSION	SOURCE
British Columbia		1951 – 1975	E	Ricker, Can. J. Fish. Aquat. Sci. 38, 1636 (1981).
Chum salmon – *Oncorhynchus keta*				
Japan			PP and E	Morita, Fukuwaka, Mar Ecol-Prog Ser 335: 289–294 (2007); Fukuwaka, Morita. Evol. Appl. 1: 376–387 (2008)
Grayling – *Thymallus thymallus*				
Several lakes in Oppland, Norway		1903 – 2000 (ca. 15 years)	E	Haugen, Vøllestad, Genetica 112–113, 475 (2001).
Plaice – *Pleuronectes platessa*				
North Sea	OSPAR	1957 – 2001	E	Grift, Rijnsdorp, Barot, Heino, Dieckmann, Mar. Ecol. Progr. Ser. 257, 247 (2003).; Grift, Heino, Rijnsdorp, Kraak, Dieckmann, Mar. Ecol. Progr. Ser. 334, 213 (2007).; Rijnsdorp, Oecologia 96, 391 (1993).;
Sole – *Solea solea*				
Southern North Sea	OSPAR	1958 – 2000	E	Mollet, Kraak, Rijnsdorp, Mar Ecol-Prog Ser 351: 189–199 (2007)
Red porgy – *Pagrus pagrus*				
South Atlantic Bight		1972 – 1994	E	P. J. Harris, J. C. McGovern, Fish. Bull. 95, 732 (1997).

1B) TRENDS TOWARD INCREASED FECUNDITY/REPRODUCTIVE INVESTMENT				
AREA	OSPAR AREA	PERIOD	CONCLUSION	SOURCE
Atlantic cod – *Gadus morhua*				
North Sea and West of Scotland	OSPAR	1969 – 1970, 2002 – 2003	E	Yoneda, Wright, Mar. Ecol. Progr. Ser. 276, 237 (2004).
Northern		1978 – 2007	E (males)	Baulier *et al.,* in prep.
Southern Grand Bank		1978 – 2007	Inconclusive (females)	Baulier *et al.,* in prep.
St. Pierre Bank		1978 – 2007		Baulier *et al.,* in prep.
Haddock – *Melanogrammus aeglefinus*				
North Sea	OSPAR	1976 – 1978, 1995 – 1996	E	Wright, ICES CM 2005 Q, 07 (2005).
Plaice – *Pleuronectes platessa*				
North Sea	OSPAR	1900 – 1910, 1947 – 1949, 1977 – 1985	E	Rijnsdorp, ICES J. Mar. Sci. 48, 253 (1991); Rijnsdorp, Grift, Kraak, Can. J. Fish. Aquat. Sci. 62, 833 (2005)
Whitefish – *Coregonus lavaretus*				
Lake Constance		1963 – 1999	E	Thomas, Quoss, Hartmann, Eckmann. Journal of Evolutionary Biology 22: 88–96. (2009)

1C) TRENDS TOWARDS DECREASED SIZE AT AGE

Area	OSPAR Area	Period	Conclusion	Source
Atlantic cod *Gadus morhua*				
Southern Gulf of St Lawrence		1971 – 2001	E	Swain, Sinclair, Hanson, Proc. R. Soc. B 274, 1015 (2007).
Atlantic salmon *Salmo salar*				
Goodbout River, Quebec		1859 – 1983	E	Bielak, Power, Can. J. Fish. Aquat. Sci. 43, 281 (1986).
Pink salmon *Oncorhynchus gorbuscha*				
British Columbia		1951 – 1975	E	Ricker, Can. J. Fish. Aquat. Sci. 38, 1636 (1981); Ricker, Can. Spec. Publ. Fish. Aquat. Sci. 121, 593 (1995).
Red porgy *Pagrus pagrus*				
South Atlantic Bight		1972 – 1994	E	Harris, McGovern, Fish. Bull. 95, 732 (1997).
Whitefish – *Coregonus clupeaformis*				
Lesser Slave Lake		1941 – 1975	E	Handford, Bell, Reimchen, J. Fish. Res. Bd. Can. 34, 954 (1977).
Whitefish – *Coregonus lavaretus*				
Lake Constance		1947 – 1997	E	Thomas, Eckmann, Can. J. Fish. Aquat. Sci. 64, 402 (2007)
Whitefish – *Coregonus palaea*				
Lake Joux, Switzerland		1981 – 2001	E	Nussle, Bornand, Wedekind. Evolutionary Applications in press. (2009)

9 Future of the Study Group

The originally planned three-year lifespan of the Study Group would suggest that the group would be dissolved in 2009. The group recognized that good progress in addressing the terms of reference had been made and that significant challenges in bridging the gap towards the management of concrete fish stocks remain. The group hence unanimously supported the proposal that the Study Group would be given a new three-year term.

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Annex 2: Agenda

Monday 30 March 2009 — morning and afternoon:

Work on the two manuscripts initiated during the group's previous meeting (core groups only)

Tuesday 31 March 2009 — morning and afternoon:

Introduction; Research updates and discussion triggers

Wednesday 1 April 2009 — morning and afternoon:

Introductory talks to the "selection differentials" project; Data-status presentations for individual stocks

Thursday 2 April 2009 — morning:

Action plan for the "selection differentials" project; Introductory talk about linking FLR and FIE, followed by a discussion

Thursday — afternoon:

Action plan for the "selection differentials" project (continued); Future of SGFIAC; Discussion of the two SGFIAC 2008 manuscripts

Friday 3 April 2009 — morning and afternoon:

Writing of the report and planning of future activities (chairs only)

Annex 3: SGFIAC terms of reference for the next meeting

The Study Group on Fisheries Induced Adaptive Change [SGFIAC] (Co-Chairs: M. Heino, Norway, U. Dieckmann, Austria, A. D. Rijnsdorp, The Netherlands) will meet in XXX from XX – XX April 2010 (prior to the meetings of AFWG and WGNSSK) 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.

SGFIAC will report by 15 May 2010 for the attention of SCICOM and ACOM.

Supporting Information

Priority:	The activities of the SGFIAC Study Group 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. SGFIAC 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 SGFIAC are ongoing, and corresponding resources have been committed by the engaged institutions. The resources for convening the annual SGFIAC meeting are negligible.
Participants:	SGFIAC is normally attended by 15–25 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 Fishery Systems (WGFS). 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.