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Genetic consequences of fisheries and fisheries management

Report from a multi-disciplinary workshop in
Rönne, Bornholm, 25–26 October 2006

Johan Dannewitz, Ann-Britt Florin, Erik Petersson, Einar Nielsen, Eydfinn Magnussen, Geir Dahle, Juha Merilä, Mikko Heino, Skúli Skúlason, Teija Aho, Torbjörn Järvi & Torild Johansen

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Content

Preface

This report summarizes talks, discussions and conclusions from a multidisciplinary workshop on genetic consequences of fisheries and fisheries management held in Rönne, Bornholm in October 2006. The idea of arranging the workshop was put forward during an expert-seminar at Hólar College on Iceland in 2004 arranged by the Nordic Council of Ministers, where selected expert scientists discussed the current knowledge regarding the effects of commercial fishing activities on the genetic diversity of wild, marine fish species in Nordic waters.

Financial support for arranging the workshop was kindly provided by the Nordic environment and fishery co-operation (MiFi) working group. The workshop was intended for fishermen, scientists, decision makers, managers and other stakeholders from the Nordic countries. The main objectives were to 1) improve communication between parties involved in fisheries management, 2) Present current knowledge regarding genetic consequences of fisheries, and highlight the importance of including genetic/biological data in the management of exploited fish species, and 3) agree upon recommendations on how genetic considerations could be implemented in management and decision making processes.

The workshop was arranged by a group of scientists from the Nordic countries consisting of Dr. Johan Dannewitz (project leader), Dr. Ann-Britt Florin, Doc. Erik Petersson, Dr. Einar Nielsen, Dr. Eydfinn Magnussen, Dr. Geir Dahle, Prof. Juha Merilä, Dr. Mikko Heino, Dr. Skúli Skúlason, Dr. Teija Aho, Prof. Torbjörn Järvi and Dr. Torild Johansen. Invited external speakers were Dr. Anna Gårdmark, Dr. Dorte Bekkevold, Dr. Dylan Fraser, Dr. Michael Hansen & Dr. Michele Casini. The report was edited by Johan Dannewitz, Ann-Britt Florin and Erik Petersson.

Summary

A multi-diciplinary workshop on genetic consequences of fisheries and fisheries management was held in Rönne, Bornholm in October 2006. The main objectives of the meeting were to 1) improve communication between parties involved in fisheries management, 2) present current knowledge regarding genetic consequences of fisheries and highlight the importance of including genetic/biological data in the management of exploited fish species, and 3) agree upon recommendations how genetic considerations could be implemented in management and decision making processes. The following topics were discussed in detail: 1) Identification of populations and management units, 2) Co-management of fish resources as an alternative management strategy, 3) Evolutionary consequences of fisheries, 4) Genetic effects of fish releases, 5) Effects of fisheries on other species in the ecosystem, and 6) Genetic effects of marine protected areas. For each topic, invited experts gave plenary talks, followed by discussions by all participants in smaller working groups.

The following recommendations were agreed upon by the participants:

- Management units should be biologically relevant and identified following the ESU concept. Improved information based on population genetics approaches should be used in all assessment. There is a need for an adaptive management philosophy where managements units are re-evaluated according to changed conditions and new knowledge. Finally, a biological atlas of suitable managements units for exploited species should be made, preferably by an ICES working group.
- A prerequisite for successful co-management is that the stakeholders taking part in the work actually have influence on the decision-making process. All Nordic countries should create an advisory board that can give recommendations how the group should be constituted. Co-management projects should be initiated also when there are no problems. It is important that all communication of information, especially scientific, within the co-management group is made in a popular way.
- Decreased fishing mortality is the prime and “safe” way to decrease/-minimise evolutionary changes. Fishing mortality patterns that either are minimally selective or resemble natural predation are likely to pose less selection pressure than the present highly selective fishing patterns. Complex size-based regulations may reduce certain selection pressures but before these are introduced, background information

should be gathered and planned regulations tested and evaluated with models, afterwards changes should be monitored.

- Stocking-policies must be more restrictive and only used as an "emergency exit". Identification and removal of the problems in the wild should always be given a high priority before any decisions about stocking are made. When stocking is unavoidable, hatchery practices should meet genetic guidelines and minimise genetic and phenotypic changes of the fish. Genetic and ecological consequences of stocking programmes should always be monitored. A review about restoration methods, which should be translated into all Nordic languages, is warranted. If restoration gives conservation concerns it is recom-mendded to adopt the ESU approach in the decision making process. Escapes from fish farms have to be prevented.
- The ecosystem approach should be implemented into fisheries management, requiring basic knowledge of population structure of affected species, and monitoring of a larger number of species, not only the target species. Levels of by catches should be reduced to limit direct impacts on non-target species. Basic research on trophic inter-actions in marine and freshwater ecosystems should be prioritized, as should identification of indicator-species in exploited ecosystems.
- There is a need for a definition of MPA and the objective and criteria for success should be defined before establishing it.
- There is a need for an improved contact between scientists, managers and fishermen. Continued multidiciplinary workshops is one way of achieving this.

Introduction

A future challenge is to manage and protect natural resources while meeting the socioeconomic needs of a rapidly increasing human world population. This challenge is perhaps particularly evident when it comes to aquatic organisms for which exploitation rates have increased dramatically in recent decades. High exploitation rates pose threats to biological diversity at several levels, including diversity at the gene level. For example, high fishing pressures may reduce population sizes to levels where inbreeding and loss of genetic variability become serious problems. Fishing in areas which are used by several populations of the same species (mixed stock fisheries) may result in overexploitation or even extinction of genetically unique populations. Furthermore, the high and selective mortality induced by fishing is likely to cause evolutionary changes in functional traits such as growth rate and maturation age.

Stocking of fish (which is carried out for different purposes) can result in genetic changes and reduced genetic diversity of wild fish species. Stocking material produced from a restricted number of parental fishes may result in inbreeding and loss of genetic diversity, whereas stocking of non-native populations may result in loss of local adaptations due to genetic mixing between the introduced fish and wild conspecifics.

For all management issues listed above, there are obvious reasons why genetic information needs to be taken into account. One of the main objectives of this workshop was to highlight the importance of including genetic information, e.g. information on population structure, in the development of management strategies for exploited fish species. It is also clear that fisheries management cannot be limited to management of single target species. The interconnection between all organisms in the ecosystem will have consequences for how management and conservation programmes should optimally be designed. High fishing pressure on a single target species is likely to have effects also on other species in the ecosystem. The development from “single-species” to “ecosystem-based” management has only begun, and it is not always clear how the ecosystem approach should be implemented in traditional fishery management. Clearly, it will require, among other things, increased knowledge about population genetic structure of non target species in exploited ecosystems.

The following topics were discussed during the workshop: 1) Identification of populations and management units, 2) Co-management of fish resources as an alternative management strategy, 3) Evolutionary consequences of fisheries, 4) Genetic effects of fish releases, 5) Effects of fisheries on other species in the ecosystem, and 6) Genetic effects of marine protected areas. For each topic, invited experts gave plenary talks, followed by discussions by all participants in smaller working groups. This document provides a short background and summaries of all group discussions including recommendations agreed upon. The report also includes an evaluation of the meeting made by the participants, including suggestions on how similar meetings in the future could be arranged. A complete programme with schedule, discussion topics for working groups, abstracts, and a list of participants (with contact information) can be found in the appendices.

Topic 1. Identification of populations and management units

1.1 Background

Most exploited fish species are divided into genetically distinct local populations that evolve more or less as independent units (depending on the amount of genetic exchange between them). Natural selection may favour different gene variants in different geographic areas, and this could give rise to local adaptation, i.e. populations become adapted to different environmental conditions. Fishing and aquaculture may affect the genetic population structure in several ways. For example, extinction of genetically unique populations will result in loss of local adaptations and a reduced overall genetic diversity. Therefore, genetic population structure must be identified and accounted for in the management of exploited fish species.

1.2 Definition of management units

The definition of management units varies considerably between countries and regions. In Nordic countries the management unit is often equivalent to the fished stock, and this may or may not mirror the true population structure. Freshwater and anadromous species are often managed according to rivers and lakes, which in many cases can be viewed as biologically relevant management units as they often mirror the true population structure. For marine species, the unit is more arbitrary defined, for example according to the ICES subdivision system. The Icelandic cod, for example, is managed as one stock but recent otolith and genetic studies indicate that there are two distinct populations; one northern and one southern. Many marine and anadromous species perform migrations and populations often overlap in their spatial distribution, which makes identification of management units below the species level problematic. For fish species in general, both freshwater and marine, their economic importance will often define to what level and how detailed they are characterised and managed.

In USA, more biologically relevant criteria are often used when defining management units. In the Endangered Species Act, the Evolutionarily Significant Unit (ESU) is used and given the same status as a species.

The ESU concept was developed to provide an objective approach to identify units for protection and management below the species level. An ESU is often defined as a population or a group of populations that “contribute substantially to the overall genetic diversity of the species” and/or “show deep phylogenetic distinctiveness”. The goal is to maintain diversity and future adaptive potential within species and secure ecological viability of populations. In Canada, a somewhat similar entity, the Designationable Unit is used. It is defined depending on risk situation and spatial discreteness.

All kind of information, e.g. data on neutral genetic variation, morphological and life history data, fishermen’s knowledge etc, can be used when identifying ESUs. The concept is not without problems, however. Managers will face difficult decisions concerning for example at what level we adequately maintain diversity within a species. Also, socioeconomic conciderations will almost always put limitations on management efforts. Criteria for identifying ESUs will thus change from case to case, depending on species characteristics and other circumstances.

1.3 How can biologically relevant management units be identified?

Management units should be identified using a set of standardised criteria following the ESU concept. As mentioned above, these criteria may differ from case to case depending on the situation, e.g. different criteria for freshwater, anadromous and marine species. All available data should be incorporated. Phenotypic studies could give valuable information if there is a sound genetic basis for the studied traits. Improved information on genetics should be used in all assessment (also in ICES standard advice) together with standard biological methods to get a synergetic positive effect on the accuracy of the assessment. Management units should be re-evaluated over time following an adaptive management philosophy. Better methods but also changed conditions (environmental change, changed exploitation rates etc) may require changes in the management strategy.

Problems that arise during the process have to be solved in a flexible way. For example, management of migrating anadromous and marine species with spatially overlapping populations is likely to be problematic. Different solutions to this could either be to restrict fishing to the spawning grounds (mainly suitable for terminal fishing of anadromous species), or Mixed Stock Analysis using genetic tools to determine the proportions of different populations in the catch. In general, the prioritising among populations for future management is often problematic because resources are almost always limited. Salmon may constitute an example. Should we preserve a few large populations, or put more effort in managing the rare unique ones? The best strategy is depending on the objective.

Historical information is important here since rare populations today may have been important earlier (e.g. to facilitate genetic exchange between populations), i.e. their current status as rare may not be natural but reflects anthropogenic impacts.

There are caveats with the use of genetic markers to identify management units which should be recognised. For example, there can be relevant biological differences although no neutral genetic differentiation can be detected. This is a problem in marine species where neutral differentiation is low compared to anadromous and freshwater species. This means that several markers, not only neutral markers like microsatellites, should be used. Another problem is that DNA-analysis can be too expensive for economically less important fisheries, and it is important not to give advice to use genetic methods if they are not necessary.

1.4 Recommendations

- Management units should be biologically relevant and identified following the ESU concept, using standardised criteria and taking all available data into consideration (historical information, neutral and adaptive genetic differentiation, phenotypic differentiation, fishermen's knowledge etc).
- Improved information based on population genetics approaches should be used in all assessment.
- An adaptive management philosophy needs to be adopted, where managements units are re-evaluated according to changed conditions and new knowledge.
- A biological atlas of suitable managements units for exploited species should be made, preferably by an ICES working group. First, an educated guess of biological relevant units based on all available data is made. Second, the units should be refined according to practical limitations. Third, a list of information that is lacking should be made, and fourth, the units should be continuously updated.

Topic 2. Co-management as an alternative management strategy

2.1 Background

Co-management implies that fishermen and other stakeholders (scientists, managers, governments etc) are involved in decision-making processes and the development of management strategies. One advantage with this way of managing aquatic resources is that decisions concerning for example exploitation rates tend to get higher acceptance among all stakeholders. Previous experiences indicate that co-management has the best potential to work on a local scale. Freshwater systems and coastal regions seem to be areas where opportunities for success are the best. A contributing cause could be that we generally have a better knowledge about the biology of freshwater fish as compared to marine species, which makes it easier for scientists to give clear recommendations and get support for their ideas among other stakeholders. Multi-national fisheries on marine species on international waters most likely are to politically contaminated for co-management. Politicians from different countries negotiate during international meetings and stakeholders from the different countries will not have direct influence on the decision-making process. Under these conditions, co-management is unlikely to work.

2.2 Who decides who is ‘co-‘?

The co-management group has to be focused on a specific problem (species and/or area) and that will often determine the composition of the group. For some species, the anglers might be the most important (most affected) stakeholder, whereas in other cases net-fishermen or trawlers might be the ‘key’ stakeholder. A large group, consisting of several different stakeholders, is very attractive from a democratic point of view. Several interest groups will in this way be part of the discussions and the risk that someone, that actually is affected, will be forgotten and left out is reduced. One draw-back can be that the work may progress slowly.

Which stakeholders should then be involved and/or invited to take part in the process? In some cases the solution is simple and obvious. In a ‘bottom-up’ initiative to the co-management, one stakeholder contact managers and/or decision-makers in order to get a grip on a situation, for example how to regulate the fishing in a defined area. Alternatively, two or more stakeholders might first contact each other and later on governmental institutions on different levels. In such cases, the question is defined by the stakeholder and there might not be need for any other action than just support the stakeholders in their work. In a 'top-down' initiative to co-management, it is more important which stakeholders are being invited. One way to solve this might be to have a regional or national advisory board consisting of representatives from all possible organisations; governmental fishery board, angling associations, fishermen's organisations, environmental organisations, land owners etc. The advisory board can give recommendations how the co-management group should be constituted and who will lead the work.

It is important to note that co-management is a way of co-operation, all stakeholders should be prepared to both give and take. The rank between the stakeholders should be as equal as possible, and all involved should have a considerable influence on the decision-making process. There is always a risk that a certain group is favoured in the work, and it is important that all participants are aware of this.

A few co-management projects have already been initiated in Nordic Countries. In Swedish coastal waters, for example, there are three ongoing projects, and these differ in stakeholder participation, level of co-operation, involvement of authorities and resource focus. One of the projects concerns fishermen who trawl for northern shrimp (*Pandalus borealis*) in a marine protected area in the northern archipelago of Skagerrak. The fishermen, scientists and regional and local authorities have agreed on a management plan for a sustainable fishery and nature conservation. The plan includes restrictions on gear and access to ecologically sensitive areas. The fishery has been certified for a Swedish consumption label and the fishermen have participated in a marine ecology course arranged by university scientists.

2.3 Recommendations

- One of the most important factors in co-management is whether the stakeholders taking part in the work actually have influence on the decision-making process. If the stakeholders do not have any power in the group, the meetings, and the time and energy spent on co-management is a waste of time.
- An advisory board should be created in each Nordic country. When the need for co-management arises for a species in a certain area, the advisory board can give recommendations how the group should be constituted. The advisory board should meet two or three times a year.
- Co-management projects should not only be initiated when there are problems approaching. The basic conditions for a good communication and a fruitful collaboration between different stakeholders are

likely better once a problem arises if the co-management project is already ongoing.

- It is important that all communication of information within the co-management group is made in a popular way. Especially scientists have to make an effort in this matter.

Topic 3. Evolutionary consequences of fisheries

3.1 Background

Exploitation rates on fish stocks have increased considerable during recent decades, and statistics from the Food and Agriculture Organization of the United Nations show that an increasing proportion of the world fish resources are overexploited, depleted, or recovering from depletion. Fishing induces high mortality, and the harvesting is not random: due to the size-selective fishing practices we employ, we are selectively killing large and fast-growing individuals. Also, fishing mortality is often non-random with respect to geographical location. The high and selective mortality induced by fishing has the potential to cause evolutionary changes in several important traits, such as growth rate, maximum length, age and size at maturation, and migration behaviours. These changes can have severe consequences for the exploited stock itself, e.g. reduced recruitment rates, but also on other species in the ecosystem through changed ecological interactions in for example the food web. Fishing has also been found to change the species composition in some ecosystems. Evolutionary changes are likely to affect the profitability due to lower yields and a lower commercial value. Evolutionary changes in life history or behaviour are likely to have consequences for maximum potential population growth rate at low density, and may thus have important consequences for the ability of stocks to recover from overexploitation.

Evolutionary changes caused by fishing have been observed in exploited stocks of several fish species, for example earlier maturation at a smaller size in Atlantic cod, haddock, plaice, sole and American plaice (known also as long rough dab in Europe). Empirical studies also suggest evolutionary changes in somatic growth rate. Selective fishing mortality is likely to affect also other traits, but there are no unequivocal results from exploited populations in the wild published so far. However, several research programmes on this issue are ongoing and additional evidence for life history evolution in exploited fish species are likely to appear in the near future. There are also alternative management options currently being evaluated in different theoretical models. Empirical evaluations of these alternative management options should be prioritized in future research.

3.2 Recommendations

- Decreased fishing mortality is the prime and “safe” way to decrease/minimise evolutionary changes.
- Fishing mortality patterns that either are minimally selective or resemble natural predation are likely to pose less selection pressure than the present highly selective fishing patterns (large individuals are prime targets) that are usually opposite to the natural mortality pattern (large individuals are least vulnerable).
- Complex size-based regulations (e.g., protected slots, minimum and maximum allowable size limits) may reduce certain selection pressures.
- Before selective regulations of fisheries are introduced, background information should be gathered and planned regulations should be tested and evaluated with models. Changes should then be monitored (e.g. the effect of size-regulations in heavily exploited salmonid populations).

Topic 4. Genetic effects of fish releases

4.1 Background

The practice of releasing (stocking) fish into the wild is common in the management and conservation of a number of fish species. Releases are performed for different purposes, the most important being to increase the yield for commercial and recreational fisheries, to support endangered wild populations at risk of extinction or to reintroduce populations that have become extinct. There is a general concern, however, that releases of fish into the wild may constitute a threat to the genetic and ecological integrity of wild populations, and several guidelines on this subject have been produced.

Releases for improving fisheries, so-called fisheries releases, is the most common form of stocking activity, and is often initiated because the natural productivity has decreased due to e.g. habitat degradation or over-fishing . So-called “put-and-take” releases also belong to this category. Releases aimed at saving populations from extinction, often referred to as conservation releases, typically involve the use of a local broodstock for production of stocking material. In salmonid fishes, for example, hatchery programmes are frequently used for artificial propagation of endangered wild populations (so-called supportive breeding). Supportive breeding should be considered a temporary solution until the factors responsible for any population decline have been identified and removed. Unfortunately, it appears that most supportive breeding programmes are considered successful as long as the releases of hatchery fish compensate for the loss to fisheries. A serious consequence of this view is that habitat improvements to restore natural productivity are rarely performed and the populations concerned therefore become dependent on continued artificial propagation. Releases of fish are also undertaken to re-establish populations that have become extinct due to e.g. previous hydropower exploitation.

4.2 Domestication in fish culture

The rapid expansion of hatchery programmes for production of stocking material has raised concerns about how the hatchery environment may affect the fish. Hatchery produced fish may differ from their wild conspecifics for two reasons. First, artificial breeding and rearing of fish may result in an evolutionary divergence of the hatchery fish away from their wild conspecifics. The mechanisms responsible for such genetic changes are alterations of sexual and natural selection in the hatchery, and random genetic processes during breeding. For example, by providing a predator-free environment with surplus food, the hatchery environment may select for decreased anti-predator responses and increased growth potential. Second, fish are highly phenotypically plastic, and hatchery fish may differ considerably from wild fish as most environmental characteristics affecting fish development differ between the hatchery and the wild. For example, water velocity has been shown to affect the body shape of salmonid juveniles. In fact, most important traits are assumed to be influenced to some extent by the rearing environment.

The genetic and environmental effects of hatchery culture mentioned above will have consequences for the success of hatchery fish after release into the wild. Numerous field studies have shown that hatchery produced fish have a reduced fitness as compared to their wild conspecifics. Genetic mixing between wild and released hatchery fish will therefore have negative effects on fitness of whole populations, and this has been the main criticism against using stocking as a management practice. It is possible to minimise changes in the hatchery environment (both genetic and phenotypic), for example by rearing the fish under more natural conditions, releasing them into the wild at a younger age and/or using native, wild individuals to produce the hatchery fish. However, such actions will only slow down the process, not prevent it.

Escapes of farmed fish not intended for release is a problem in many areas. Farmed fish have typically been kept under artificial conditions for many generations and selected for economically important traits, and these domesticated fish may invade and interact with locally adapted wild populations, an example being the frequent escapes of farmed Atlantic salmon in the North Atlantic which threaten many wild salmon populations.

4.3 Habitat restorations as an alternative

There is a trend in many countries to restore waters instead of stocking fish to increase production. Managers also tend to pay more attention to genetic conciderations when stocking is taking place, which of course is a positive development. However, restorations are resource demanding and desired effects may take time to achieve. In some small rivers in Denmark, for example, restorations have been going on for 20 years. Therefore, it is an educational and/or informational challenge to convince fishermen and others that this is the best way in the long run. There seem to be much experience and knowledge on how to restore aquatic habitats, but there is an urgent need to summarise this knowledge and make it more available to managers.

4.4 Recommendations

- Stocking-policies must be more restrictive. Releases of fish should only be performed if necessary as an "emergency exit". Identification and removal of mechanisms behind e.g. reqruitement problems in the wild should always be given a high priority (e.g. habitat restorations) before any decisions about stocking are made.
- When stocking is unavoidable, hatchery practices should be developed to meet genetic guidelines and to minimise genetic and phenotypic changes of the fish.
- Genetic and ecological consequences of stocking programmes should always be monitored.
- It would be beneficial if the Nordic Council supported a group consisting of researchers/managers from all countries to write a review about restoration methods, which should be translated into all Nordic languages.
- If restoration gives conservation concerns (e.g. removal of migration barriers resulting in contact between populations) it is recommended to adopt the ESU approach (see above) in the decision making process.
- Escapes from fish farms have to be prevented as much as possible (e.g. by using land-based aquaculture facilities).

Topic 5. The ecosystem approach and effects of fisheries on non-target species

5.1 Background

The ecosystem approach is a strategy for management of land, waters and living resources that promotes conservation and sustainable use. The approach does not aim for short-term economic gains, but aims to optimize the use of an ecosystem without damaging it. Ecosystem has been defined in Article 2 of the Convention on Biological Diversity: "Ecosystem means a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit". The scale of analysis should be determined by the problem being addressed, and could, for example, be a pond, a lake or part of a sea. The ecosystem approach requires adaptive management to deal with the complex and dynamic structure of many ecosystems. "Learning by doing" and research feedback are important corner stones, and measures may need to be taken even if cause-and-effect relationships are not yet fully scientifically established. The ecosystem approach is comprehensive in that it includes, besides all biological resources, the economic health of communities that are affected. An important characteristic of ecosystem based management is that all parties involved, including fishermen, managers, scientists etc, are preferably involved in management decisions (see "co-management as an alternative management strategy" above).

When it comes to fisheries management, the ecosystem approach is in its commencement, and much remains do be done. Since the ecosystem approach is based on the application of appropriate scientific methodologies, including methods to identify biological diversity within and among species, applying the approach will require basic knowledge of population structures, not only of target-species but all other species that are likely to be affected by the exploitation. Fishing will almost always in some way affect also non-target organisms in the ecosystem. Direct effects include, for example, by catches and destruction of benthic ecosystems due to trawling. Indirect effects include changes in trophic interactions, which have potential consequences for all organisms in the ecosystem, from plankton to sea birds. One example is the fishery on cod in the Baltic Sea, which is suspected to have affected abundances of *clupeid* *spp*. and zoo- and phytoplankton, as well as the reproductive success of the common Guillemot.

5.2 Recommendations

- The ecosystem approach should be implemented into fisheries management. This requires, among other things, basic knowledge of population structure of affected species, and monitoring of a larger number of species, not only the target species.
- Reduced levels of by catches to limit direct impacts on non-target species.
- Basic research on trophic interactions in marine and freshwater ecosystems should be prioritized.
- Research on identification of indicator-species in exploited ecosystems. For example, sprat abundance may function as an indicator of fisheries induced changes in trophic interactions in the main basin of the Baltic Sea. This makes monitoring easier and less costly. However, the use of indicator species may not be feasible in complex ecosystems with many species and many trophic levels.

Topic 6. Genetic effects of marine protected areas

6.1 Background

The concept of allocating areas where fishing is prohibited or strongly restricted is not a new idea, but the use of Marine Protected Areas (MPAs) as a tool to conserve biodiversity has become increasingly popular in fisheries management. However, genetic effects of the establishment of MPAs have rarely been examined.

There is confusion of what should be considered a MPA and therefore it is also unclear how many MPAs there currently are in Nordic countries and what the effect of them have been. Sensitive, special areas that are protected from destructive gears/activity to conserve biodiversity, for example coral reefs, are one type of MPA. The practise of closure of areas for certain times and/or certain gears has been exercised in decades in management and these areas could be considered to be another type of MPA. Areas closed to fishing for other reasons, for example military areas, oil platforms and boat trafficking areas, could be considered a third type of MPAs, as they serve as refuges for some fish species.

To evaluate the effect of a MPA the objective of the specific MPA needs to be defined. It is important to note that MPA is not, or rarely, a goal in itself; it is a tool among others to achieve specific goals. There are two main purposes for establishing MPAs: conservation and fisheries resource management. For both types, effects of MPAs have both short and long term perspectives. In theory, positive effects (genetic or otherwise) of MPAs include conserved biodiversity, preservation of peripheral or core populations, ensured reqruitement, less pronounced evolutionary effects of exploitation, preservation of representative or unique, rare and sensitive habitats, preservation of vulnerable or keystone species, and issues related to increased public awareness. However, positive examples from temperate areas are scarce and hard facts are commonly needed to convince managers and decision makers. Lack of positive examples could be due to the studied timeframe, as focus species are commonly long-lived.

Since environment is rarely static and fishes in response may change distribution and demography over time it is important to note that MPAs should not be static over time. It is also important to make sure that a chosen MPA contains a source and not a sink population. The connectivity with other areas/populations must also be considered because the effect of the MPA is affected by the dispersal/geneflow/migration pattern of the organisms. Finally, it is important to consider a relevant timeframe to obtain the goal of the MPA.

6.2 Recommendations

- There is a need for a definition of MPA from a management perspective. The objective of a MPA and criteria for success should be defined before establishing it.
- Establishment of MPAs could follow a decision maker flow-chart along lines sketched in figure 1.

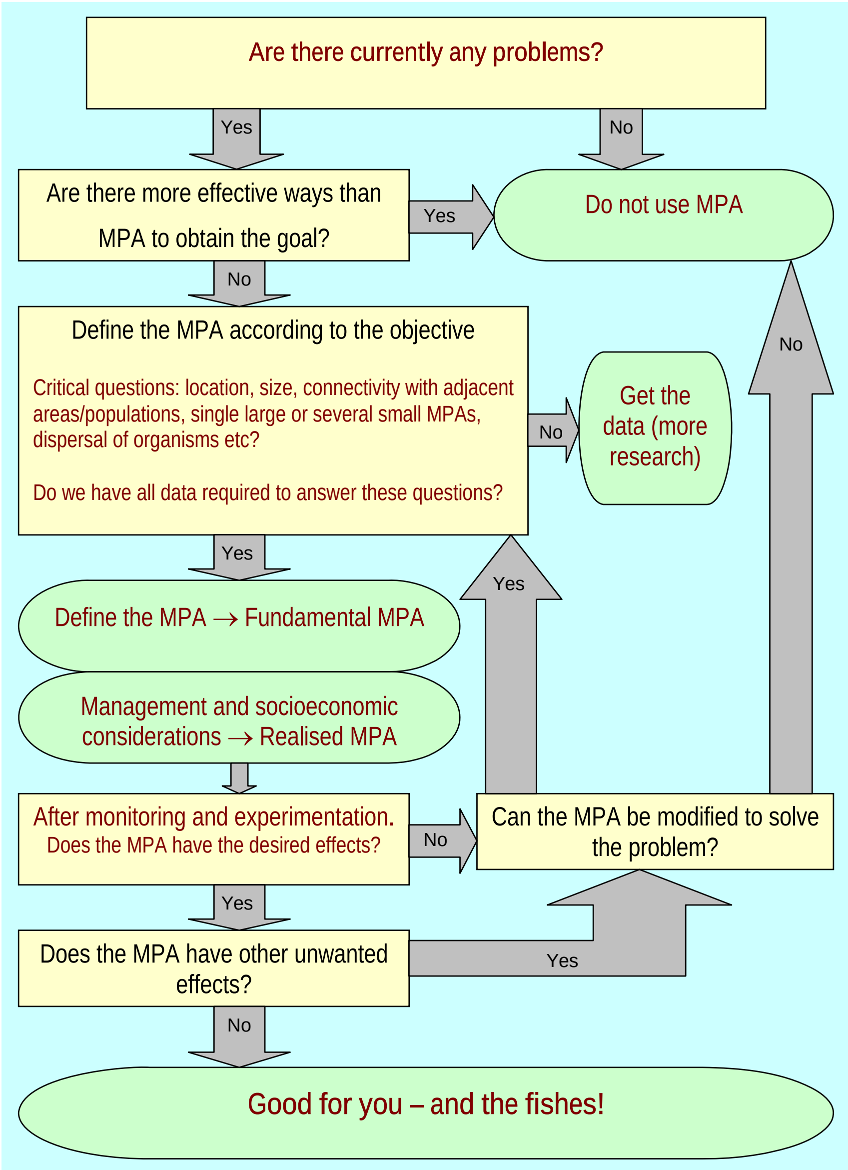

Figure 1. A decision maker flow-chart that can be used when planning and establishing Marine Protected Areas (MPAs).

Evaluation of the meeting

Scientists dominated among the participants. A few people working with management issues participated, whereas only one representative from an angler association and none from the fishermen's federations participated (see list of participants in the appendix), which was a disappointment. One way to draw more managers could be to invite a few managers to give talks on subjects directly related to the practise of their profession. To meet fishermen and their organisations, it may be necessary to initiate meetings like this on a national or regional level.

The participants were satisfied with the meeting and how it was organised. There was a good idea to include a representative from outside the Nordic countries to get a different perspective and new ideas. Perhaps also representatives from other Baltic countries should be invited to future meetings as well as politicians. All participants agreed the dialog needs to be continued. There is an increased use of genetics in fisheries management and the opportunities as well as the needs for cooperation are growing. This meeting should be repeated, and preferably financed by the Nordic Council for Ministers. The meeting should preferably be held every 2nd year, kept short (maximum of 2 days) and announced at least half a year in advance. The meeting should not be too big, people need to meet and discussions should be feasible. Around 50 persons is suitable. The time of the meeting should consider when it suits managers best. Organisation of the meeting should be rotated among countries.

Continued meetings with focus on genetic consequences of fisheries and how to implement genetic information in management are one way to improve the contact between fishermen, managers and scientists. One suggestion was to invite one or a few journalists to the meeting, and money should then be allocated to this. Presstatement should then be held before and after the meetings. The workshop report could also be distributed to national journalists by representatives in the project group. Writing of popular scientific papers by representatives in the project group could be another way to reach this goal, but also then resources must be allocated to this. A suggestion was to construct a webbased handbook for managers containing advice but also general biological information and links to relevant articles. Denmark has already started such a handbook (www.fiskepleje.dk). The basic idea and structure of the handbook could be developed by a group with representatives from all Nordic countries, and the handbook could then be published by the national boards of fisheries in all Nordic languages.

Svensk sammanfattning

Denna rapport sammanfattar föredrag, diskussioner och slutsatser från ett multi-disciplinärt möte med temat ”genetiska konsekvenser av fiske och förvaltningsåtgärder” som hölls i Rönne, Bornholm i oktober 2006. Mötet finansierades av styrgruppen för nordiskt miljö och fiskerisamarbete (MiFi) och riktade sig främst till fiskare, forskare, beslutsfattare och förvaltare från de nordiska länderna. Syftet med mötet var att 1) stärka kontakten mellan grupper involverade i förvaltningen av fiskbestånd, 2) presentera och diskutera de senaste forskningsrönen inom området och 3) ta fram rekommendationer för hur genetisk information och kunskap skall användas inom förvaltningen och i beslutsprocesser. Följande ämnen diskuterades under mötet: 1) Identifiering av relevanta förvaltningsenheter, 2) samförvaltning av fiskresurser, 3) evolutionära konsekvenser av fiske, 4) genetiska effekter av fiskutsättningar, 5) fiskets effekter på icke målarter, och 6) genetiska effekter av inrättandet av skyddade områden. Inbjudna föreläsare höll inledande föredrag varefter diskussioner i mindre grupper tog vid.

Deltagarna enades om följande rekommendationer:

- Förvaltningsenheter skall vara biologiskt relevanta och bör identifieras med hjälp av ESU- (Evolutionarily Significant Units) konceptet. Populationsgenetiska tillvägagångssätt bör användas inom all bedömningsverksamhet. Det finns ett behov av en adaptiv förvaltningsfilosofi vilket bland annat innebär att förvaltningsenheter uppdateras kontinuerligt allt eftersom omständigheter och kunskapsläget förändras. En biologisk atlas som beskriver lämpliga förvaltningsenheter hos de mest exploaterade arterna bör upprättas, lämpligtvis av en arbetsgrupp inom ICES.
- En förutsättning för en lyckad samförvaltning är att alla involverade intressegrupper verkligen har möjlighet att påverka beslutsprocessen. Alla nordiska länder bör upprätta en nationell rådgivande grupp som kan utarbeta rekommendationer för hur samförvaltningsprojekt bör planeras och genomföras. Samförvaltningsprojekt skall initieras även om inga egentliga problem föreligger. Det är viktigt med en bra kommunikation mellan de olika intressegrupperna.
- Minskad fiskeridödlighet är den enda säkra lösningen för att undvika evolutionära förändringar i hårt exploaterade bestånd. Förvaltare bör sträva efter att minska den selektiva dödligheten i fisket. Komplexa storleksbaserade regleringar av fiskeuttaget kan minska vissa oönskade förändringar, men fler teoretiska och praktiska

undersökningar krävs innan några generella riktlinjer och råd kan utarbetas.

- Riktlinjer för utsättningar måste bli mer restriktiva. När det gäller bevarande av hotade arter och populationer skall utsättningar endast användas som en sista utväg, och då under en begränsad tid. Istället bör åtgärder sättas in för att identifiera och ta bort orsakerna till problemen. När utsättningar ändå anses vara nödvändiga ska de riktlinjer som finns tillgängliga följas för att minimera genetiska och fenotypiska förändringar hos fisken. Det anses mycket viktigt att alla utsättningar följs upp för att kunna upptäcka eventuella negativa effekter i tid. En sammanställning som beskriver olika typer av biotopförbättrande åtgärder, som alternativ till utsättningar, samt dess effekter efterfrågas av många inom förvaltningen. Inom all typ av utsättningsverksamhet ska ESU-konceptet följas. Det anses mycket viktigt att satsa resurser på att förhindra rymningar av odlad fisk från fiskuppfödningar.
- Ekosystemansatsen ska i framtiden utgöra en naturlig del i förvaltningen av fiskbestånd, vilket bland annat kommer att kräva grundläggande kunskaper om populationsstrukturen hos alla arter som påverkas av fisket, inte bara målarterna. Det anses viktigt att på olika sätt minska bifångsterna. Grundläggande forskning på trofiska interaktioner i sötvatten och marina system bör prioriteras, liksom identifiering av indikatorarter i exploaterade ekosystem.
- Vid inrättandet av skyddade områden i hav och sötvatten är det viktigt att först definiera syftet med åtgärden samt kriterier för bedömning av effekter.
- Det finns ett stort behov av ökad kommunikation och samarbete mellan forskare, förvaltare och fiskare. Fortsatta möten av detta slag är ett sätt att i framtiden stärka kontakten mellan grupperna.

Appendix 1. Workshop programme

GENETIC CONSEQUENCES OF FISHERIES AND FISHERIES MANAGEMENT

Rönne, Bornholm 25-26 October 2006

Tuesday 24/10

15.00 Planning meeting (only the organising committee)

19.00 Welcome dinner

Wednesday 25/10

07.00- Breakfast

08.45 Introduction

Topic 1: Identification of populations and management units

09.00 **Recognizing and maintaining diversity within species for viable fisheries**
Dylan J. Fraser, Dalhousie University, Canada

09.45 **From guesstimate to estimate: Application of genetic markers in conservation of freshwater and anadromous fishes**
Michael M. Hansen, Danish Institute for Fisheries Research

10.30 Coffee

11.00	**Conservation of adaptive genetic variability in the wild - insights from comparative studies of marker gene and quantitative trait variation** Juha Merilä, Department of Biological and Environmental Sciences, University of Helsinki, Finland

Topic 2: Co-management of fish resources as an alternative management strategy

11.45	**Co-management of coastal fish resources in Sweden** Ann-Britt Florin, Johan Modin & Teija Aho Institute of Coastal Research, Swedish Board of Fisheries
12.30	Lunch

Topic 3: Evolutionary consequences of fisheries

14.00	**Evolutionary effects of fishing: disentangling plastic and genetic responses to fishing** Anna Gårdmark, Institute of Coastal Research, Swedish Board of Fisheries
14.45–18.00	Group discussions
19.00	Dinner

Thursday 26/10

07.00-	Breakfast

Topic 4: Genetic effects of fish releases

09.00	**Genetic effects of fish stocking** Einar E. Nielsen, Danish Institute for Fisheries Research
09.45	**Domestication in fish culture** Erik Petersson, Institute of Freshwater Research, Swedish Board of Fisheries
10.30	Coffee

Topic 5: Effects of fisheries on other species in the ecosystem

11.00	**Trophic cascade and threshold dynamic in the central Baltic Sea ecosystem: implications for cod recovery** Michele Casini, Institute of Marine Research, Swedish Board of Fisheries

Topic 6: Genetic effects of marine protected areas

11.45	**Genetic effects of the establishment of marine protected areas** Dorte Bekkevold, Danish Institute for Fisheries Research
12.30	Lunch
14.00–17.00	Group discussions
17.00-18.00	Evaluation of the meeting. General discussion about how to improve contact/collaboration between fishermen, managers and scientists.
19.00	Dinner

Friday 27/10

07.00-	Breakfast and departure

Appendix 2. Discussion topics

Wednesday 25/10

Identification of management units (Group 1)

- How is management units identified today?
- How can biologically relevant management units be identified?
- Is this feasible? Economical? Practical? Political?

Co-management of fish resources (Group 2)

- What could be the benefits/drawbacks of co-management?
- How shall co-management be undertaken?

Evolutionary changes due to fishing (Group 3)

- What are the consequences of evolutionary changes due to fishing? For conservation, for managers, for fishermen, consumers?
- Should we worry about this? If so, how could we prevent it?

Thursday 26/10

Genetic effects of fish stocking (Group 2)

- Is stocking without negative genetic effects possible?
- How should we prevent/minimize negative effects of stocking/escapes in future

Domestication in fish culture (Group 2)

- What are the benefits/drawbacks with domestication in aquaculture?
- How can the negative effects be minimised?

Effects of fisheries on non-target species (ecosystem based management) (Group 3)

- What are the effects on non-target species?
    - How can these effects be taken into account in future management?

Genetic consequences of the establishment of marine protected areas (Group 1)

- Are MPA´s good or bad for genetic biodiversity?
- Should MPA´s be placed to conserve the common or the rare variants of a species?

Evaluation of the meeting: general discussion including all groups

Increased collaboration/contacts between fishermen-managers-scientists

- Is this type of multi-disciplinary meeting one way of improving communication? What can be improved?
- Other ways to reach this goal?

Appendix 3. Abstracts

Recognizing and maintaining diversity within species for viable fisheries

Dylan J. Fraser
Department of Biology, Dalhousie University, Halifax, Canada

Virtually every exploited fish species is subdivided genetically and/or phenotypically. This differentiation is often associated with local environmental conditions (e.g. habitat heterogeneity) and/or historical processes (e.g. deglaciation). The objective of this presentation is to broadly illustrate to managers and decision makers the relevance of recognizing and maintaining such differentiation for viable fisheries. To do so, I critically address several key questions: (i) why is maintaining within-species diversity important for management? (ii) What exactly are we trying to maintain? (iii) How do we go about maintaining it? Lessons learned from historical approaches to recognizing and maintaining diversity within species (e.g. the concept of an *evolutionarily significant unit*) are used to exemplify important principles to be considered when defining management/conservation units within fish species at any given spatial scale. I then illustrate how these principles should be considered in practice through a detailed example of a migratory salmonid fish. Lastly, I address the controversial issue of how to prioritize population diversity within species to aid management. Indeed, although the loss of any one population is clearly unwanted, limited resources in the face of increasing human influences may require such prioritization for future management actions.

From guesstimate to estimate: Application of genetic markers in conservation of freshwater and anadromous fishes

Michael M. Hansen
Danish Institute for Fisheries Research, Silkeborg

Informed management and conservation of anadromous and freshwater fish populations requires answers to a number of questions. How large are populations and is there an imminent risk of inbreeding and loss of

genetic variation? How genetically unique are populations, and are populations adapted to local environmental conditions? Analysis of genetic markers can provide answers to a number of such questions, and I will present two case studies. The first concerns the North Sea houting (*Coregonus oxyrhynchus*), which was previously distributed throughout the Wadden Sea region, but which has declined drastically during the past century. Only a single indigenous population now remains, along with some introduced populations. A major rehabilitation program for the species has recently been initiated, supported by the EU LIFE program. Based on analysis of genetic markers we have estimated the effective population size of the remaining indigenous population and assessed whether it is declining, stable or expanding. Moreover, North Sea houting is closely related to European lake whitefish (*C. lavaretus*), and lake whitefish populations are found geographically close to the remaining North Sea houting population. Using genetic markers we analyse if the North Sea houting is actually genetically distinct from lake whitefish, i.e. if the two species are reproductively isolated at present and in the past. By combining the geological history of the region with genetic marker data we reconstruct the history of North Sea houting, and we show how this information can be used for evaluating the conservation priority of the species.

The second case study concerns anadromous brown trout (*Salmo trutta*) in the Norwegian Hardanger Fjord. The populations in the fjord have declined drastically during the past decade, presumably due to infestation by salmon lice accummulated in salmonid net-pen farms. Using genetic markers we ask if all populations are of similar size and contribute equally to migration among populations, or if specific key populations can be found, which are the main contributors to migration and are consequently of primary importance for future rehabilitation of the fjord populations. Moreover, we analyse genes involved in the immune system (Major Histocompatibility Complex (MHC) Class I genes) and are known to be subject to natural selection. We investigate if the distribution of genetic variation at MHC genes suggests local adaptation. Finally, we show for both the North Sea houting and brown trout cases how the knowledge obtained using genetic markers can be directly incorporated in management and conservation programs, both by providing information on the demographic status of populations and by providing a framework for prioritising populations for conservation.

Conservation of adaptive genetic variability in the wild - insights from comparative studies of marker gene and quantitative trait variation

Juha Merilä
Department of Biological and Environmental Sciences, University of Helsinki, Finland

Quantitative traits are those functional characteristics (e.g. body length or weight) which vary over a continuum. They are typically heritable and encoded by several different genes, and therefore, are also known as polygenic traits. The amount of genetic variability in quantitative traits within and among different populations can be estimated from pedigrees or breeding experiments. The information gained using quantitative genetic methods is fundamentally different from that gained by analyses of neutral marker genes such as microsatellites. Most importantly, while the neutral marker genes allow inferences about population history and demography, quantitative genetic analyses allow inferences about the adaptive potential of traits and populations, as well about degree of local adaptation among populations with respect to genes coding quantitative traits of interest. Therefore, information obtained from quantitative genetic studies of wild populations is highly relevant to conservation biology and management: this is information about genetic variation in traits influencing individual and population fitness. In my presentation, I aim to provide a short overview of what is currently known regarding the variation in genes coding quantitative traits among different populations of the same species. I will do this by focusing on comparative studies of quantitative genetic and marker gene differentiation, and reflect upon their utility in management context.

Co-management of coastal fish resources in Sweden

Ann-Britt Florin, Johan Modin & Teija Aho
Institute of Coastal Research, Swedish Board of Fisheries

Integrated co-management implies that fishermen and other stakeholders should be included in the management process. This study compares three current co-management projects in Swedish coastal waters. The aim is to discuss implications of local co-management on ecosystem based management. The projects differ in stakeholder participation, level of co-operation, involvement of authorities and resource focus. One project involves a local trawl fishery for vendace (Coregonus albula) in the northernmost part of the Gulf of Bothnia, the Bothnian Bay. Management decisions have partly been delegated to the concerned fishermen who annually agree on fishing restrictions (effort, no-take zones). Another project concerns fishermen who trawl for northern shrimp (Pandalus borealis) in a marine protected area in the northern archipelago of Skagerrak. The fishermen, scientists and regional and local authorities have agreed on a management plan for a sustainable fishery and nature conservation. The plan includes restrictions on gear and access to ecologically sensitive areas. The fishery has been certified for a Swedish consumption label and the fishermen have participated in a marine ecology course arranged by university scientists. These projects are contrasted with an owner-based co-management project the Baltic, where the prime goal has been to harmonise gear restrictions and allocation of fishing rights to non-owners. The various approaches for co-management, the objectives and participation are compared and the potential implications for fish resource management are discussed.

Evolutionary effects of fishing: disentangling plastic and genetic responses to fishing

Anna Gårdmark
Institute of Coastal Research, Swedish Board of Fisheries

Marine fisheries kill a lot of fish, and the killing is not random. Current fishing practices selectively catch large and fast-growing individuals. This high and selective mortality makes fisheries into a large-scale evolutionary experiment, where fishing is a selection pressure that can cause genetic changes in species' traits (i.e., evolution). If traits such as growth rate and size at maturation are heritable, the strong selection pressure imposed by fisheries will lead to evolution of these traits. Experimental results show that (i) size-selective fishing can cause trait evolution in laboratory as well as wild populations, (ii) these changes can occur rapidly and (iii) the trait changes affect fisheries yields. A novel method that disentangles trait changes that are likely to be genetically based from purely environmental variation has enabled analyses of trait changes also in commercially exploited stocks in the wild. The majority of stocks analysed with this method show changes in maturation patterns in response to the high exploitation. Therefore the question no longer seems to be *if* evolutionary responses to fishing occurs, but at what rate, and what to do about it. In this talk I will review the theoretical predictions, experimental evidence, and recent analyses of fisheries-induced trait evolution, and discuss potential implications and options for managing fisheries on evolving populations.

Genetic effects of fish stocking

Einar E. Nielsen
Danish Institute for Fisheries Research, Silkeborg

Fish stocking has for many years been considered a fast and effective option to fisheries management for assuring harvestable stock sizes for dwindling freshwater, anadromous and marine fish populations. However, stocking has a number of potential negative effects on the genetic composition of wild populations, which have to be weighted against potential benefits before initiating a release program. The negative consequences depend critically on the source and number of fish stocked, but also on hatchery practices related to the production of juvenile fish for release. We here provide an overview of potential adverse genetic effects associated with different methods for stocking ranging from classical "hatchery releases" of non-native fish subject to artificial breeding for many generations, to "supportive breeding" of offspring from local wild caught breeders. We outline specific problems related to differences in genetic population structure and population sizes among different species. Further, we present case studies documenting the direct and indirect genetic impacts of releases on wild populations. Finally, we provide guidelines for when where and how stocking could be applied to minimize negative genetic effects.

Domestication in fish culture

Erik Petersson
Institute of Freshwater Research, Swedish Board of Fisheries

Whenever an animal species is brought from its wild environment to an environment mastered by the man, it will be influenced by this. How big the change will be in the long run depends on (1) the selective regime, i.e. how much the new environment differs from the natural one; and (2) how long time, i.e. how many generations the animal species has been under human control. There are a transition from wild to domestic; the animals can be raised at zoos, raised commercially (partly domesticated), truly domesticated or even feral (gone wild again). In this presentation I will try to adapt the domestication terminology on sea-ranched salmon and trout. A domesticated animal differs from its wild conspecifics in several aspects, there are differences in behaviour and morphology. A domesticated animal behaves differently towards predators, has lower levels of aggressiveness, another social behaviour, etc. The growth rate might be higher, the body proportions and coloration might differ. Even if the significant differentiation between wild and domestic strain of the same species take many generations to develop, some changes are apparent after just one generation. This means that an animal that has been reared in captivity is more or less adapted to this new environment and has reduced probability of surviving in the wild, compared to an animal born and raised in its natural enviroment.

Trophic cascade and threshold dynamic in the central Baltic Sea ecosystem: implications for cod recovery

Michele Casini
Institute of Marine Research, Swedish Board of Fisheries

In marine systems an increasing problem is constituted by the man-made removals of large fish predators, like cod and tuna, which have shown to affect other organisms indirectly via cascading effects through the food web. Whether these cascading effects are easily reversible or not is still an open discussion. In the Baltic Sea, during the past two decades, cod dropped due to high fishing pressure and recruitment failure caused by oxygen deficiency in the main basins. The collapse of cod triggered a chain of events cascading down trough the food web: the abundance of cod preys, the planktivorous sprat, increased dramatically whereas zooplankton as well as phytoplankton biomass and community composition markedly changed. Due to density-dependent mechanisms acting on sprat growth, also piscivorous birds (e.g. the common guillemot) were affected by the ecosystem changes. Along with these top-down control mechanisms, in the Baltic Sea the population dynamics and the ecosystem configuration have also shifted as a function of cod biomass. The system shows a threshold dynamic with a low-cod/high-sprat configuration displaying a clear trophic cascade and a high-cod/low-sprat configuration where the trophic cascade is diluted by other effects. The occurrence of an ecological threshold in marine systems implies that a reduction of anthropogenic effects may not necessarily result in the positive effects sought-after. This fact implies a reduced chance of cod recovery in the Baltic Sea and will result in increased problems for fisheries management.

Genetic effects of the establishment of marine protected areas

Dorte Bekkevold
Danish Institute for Fisheries Research, Silkeborg

EU countries have through Ospar committed themselves to establishing marine protected areas (MPAs), defined as areas of land and/or sea dedicated to the protection and maintenance of biological diversity as well as natural and associated cultural resources. 'Protection' commonly translates into more or less complete fisheries closure, either on target species or entire areas. Apart from as a means for conserving 'inherent' values of biodiversity, it is envisaged that establishment of MPAs can present a direct tool both in short-term (less than five years) and longer-term (more than ten years) fisheries management, and may even represent an alternative to quota-based strategies. Although MPA planning is now slowly beginning to take shape in temperate regions, evaluations of effects on fisheries resources are still scarce. To evaluate effects of MPA establishment it is central to ask what MPAs actually protect; ranging from genetic variation over stocks/populations to species, habitats and ecosystems. Although genetic variation ultimately is the building block of ecosystem functioning, few attempts have been made to evaluate genetic effects of MPA establishment. The presentation will give an overview of potential and demonstrated genetic effects of MPAs, also in relation to predicted short- and long-term consequences to fisheries, and will give recommendations for how genetic criteria should be taken into consideration when planning and evaluating MPAs as a tool for managing fisheries sustainable.

Appendix 4. Participants and contact information

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